UNESCO

The Courier

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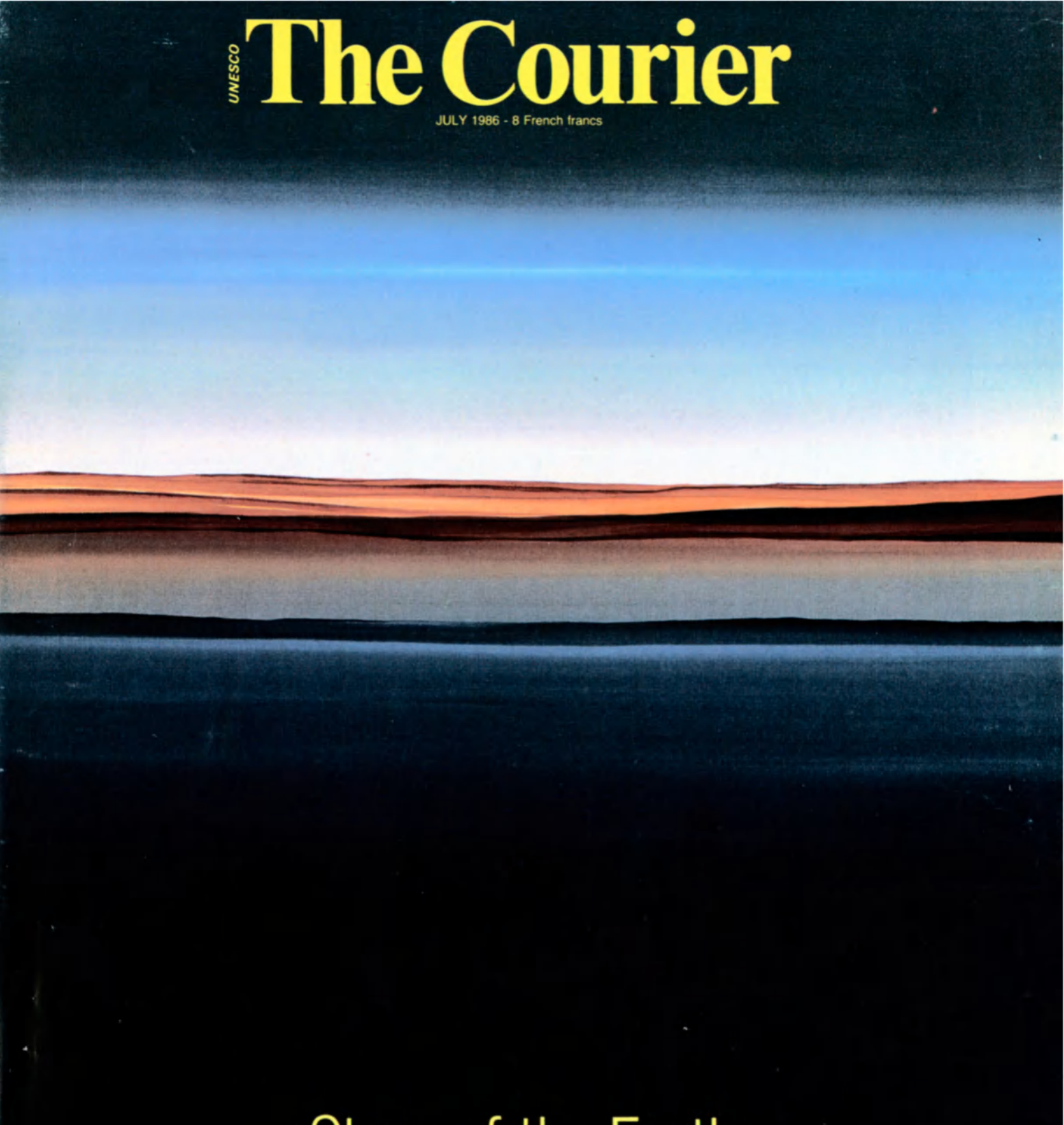

Story of the Earth

Photo Arnaud Borrel © Gamma, Paris

A time to live...

45 Mexico
To the rescue

Earthquakes are a grim fact of life for the people of Mexico. Mexico City, one of the world's largest and oldest capital cities, is situated on the southern Mexican plateau in an area of volcanic activity and faulting of the Earth's crust related to the shaping of the continental areas to the north and south.

In September 1985, Mexico City was shaken by a powerful earthquake which caused severe damage in the heart of the metropolis. In an unprecedented effort of international solidarity, rescue teams from many countries came to Mexico City to help in the work of rescuing and caring for the many victims.

UNESCO
The Courier
A window open on the world

Editorial

SEEN against the immensity of the Universe, the Earth we live on is a tiny speck of rock and metal. The third planet of the Solar System, counting outward from the Sun round which it orbits at a speed of 29.8 kilometres per second, the Earth is located between Venus and Mars, at just the right distance from the Sun (149,573,000 kilometres) to avoid being baked in perpetual heat or frozen in unending cold.

In this issue of the *Unesco Courier* our purpose is to offer our readers a simple description of the genesis of our planet and of the major geological mechanisms that regulate its restless churning. For though we call the land surface we live on *"terra firma"*, the great continental plates are in constant motion. Sometimes these plates collide, buckling at the point of impact into mighty mountain ranges; at times they are shaken by violent, shuddering earthquakes; at times the internal furnaces spew out molten rock in awesome volcanic eruptions. And all the while new crust is forming on the ocean floor and old crust is being sucked down to be recycled in the banked fires of the mantle.

In terms of geological time, man is a newcomer to this planet. If we imagine the 3,900 million years since the Earth's crust solidified as one calendar year, then *Homo sapiens* only appeared on the scene on 31 December at about eight and a half minutes to midnight (100,000 years ago).

In the very last half second of our condensed time scale, man has himself become a major geological force capable of deteriorating or even destroying the environment in which he lives. The damage that human beings inflict upon the environment is mainly due to ignorance. We still do not know enough, for example, about the long-term effects of the widespread use of chemical fertilizers and pesticides, how to prevent the spread of man-induced desertification, or how best to handle our newest energy source—nuclear power.

With its major international science programmes Unesco is in the forefront of the battle to keep our planet habitable. Although there may well be other Earths in the vast expanses of the Universe, if they exist they are well beyond our reach. We must look after planet Earth; we have nowhere else to go.

N.B. We suggest that this issue be read in conjunction with two other recent issues of the Unesco Courier: *"The Story of the Universe" (September 1984), and "The New World of the Ocean" (February 1986).*

Several of the photographs and diagrams in this issue of the Unesco Courier *are reproduced by courtesy of the Geological Museum, London, to whom we express our grateful thanks.*

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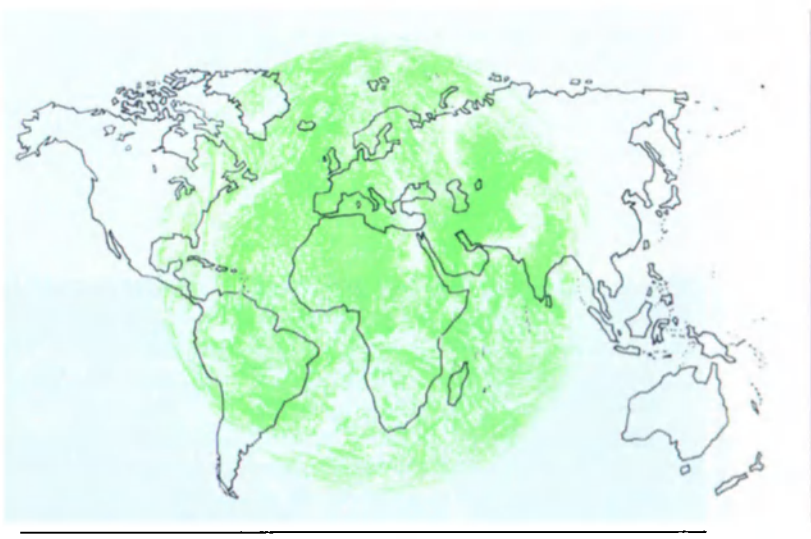
July 1986
39th year



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The genesis

IN the beginning there was nothing at all. Space, time and the matter of the Universe we live in were created together in a superdense fireball, some 15,000 million years ago, a fireball which we call the "Big Bang". As the Universe expanded and cooled, matter became spread more thinly until huge clouds of hydrogen gas began to clump together, breaking up and collapsing inwards to form stars and galaxies. By about 10,000 million years ago, galaxies like our own Milky Way system, each containing up to a few thousand million stars, were established as the basic units of the Universe. Within each galaxy stars are born, live and die, wheeling their long orbits around the galaxy's centre, while the galaxies themselves are carried ever farther apart as the Universe continues to expand.

Our Sun and Solar System are typical products of the galactic environment, but our Sun was not one of the first stars to shine in the cosmic night. Those earliest stars contained *only* hydrogen and a little helium; all the other elements have been created by nuclear reactions inside stars and scattered through space when those first stars exploded. So when our Sun formed, only a little over 4,500 million years ago, it formed out of a cloud of hydrogen gas well laced with other materials such as iron, carbon, oxygen and nitrogen—materials that settled out of the collapsing gas cloud to form the planets.

The planets of the Solar System differ from one another chiefly because of their distances from the Sun. Those closest to the forming young Sun were subjected to the greatest heat, and this drove off into space many light materials. This is why Mercury, Venus, Earth and Mars are small, rocky objects. Far out from the Sun's furnace, however, even light gases such as methane and ammonia could be trapped and held by a forming planet. So the giant planets, Jupiter, Saturn, Uranus and Neptune, probably contain the same amount of rocky material as the Earth, but this is buried deep beneath the vast layers of their gaseous atmospheres. They need not concern us here, but it is interesting and informative to make some comparisons between our own home in space, Planet Earth, and our nearest neighbours, Venus and Mars.

The small cloud of material that collapsed to form our planet, within the greater cloud that was collapsing to form the Solar System, was probably made up chiefly of silicon compounds, iron oxides and magnesium oxides, with just a small trace of all the other elements, including those that are so important to life.

As the Earth formed, it grew hot. First, gravitational energy was turned to heat as particles rained down and smashed into the proto-planet. In addition, radioactive elements inside the core of the growing planet contributed their share of warmth as they decayed into stable elements—a process which continues at a slower rate today.

The young, iron-rich planet must have been largely molten in the first tens or hundreds of millions of years after it formed, and as a result molten globules of iron forced their way downwards to the core of the Earth through the lighter, rocky material, which was left to float on top and provide a solid skin as the crust cooled. The material of the crust on which we live is not typical of the material that makes up the bulk of the Earth—and the material of the atmosphere that we breathe is even less representative of the whole planet.

The crust of the Earth contains 6 per cent iron, but the planet as a whole contains 35 per cent; silicon, which makes up only 15 per cent of the mass of the planet, forms 28 per cent of the crust, combined with oxygen to make silicate rocks. The lightest rocks, chiefly granite, make up the bulk of the continents, but the ocean floor consists of basalt, which is rather heavier.

From the surface to the centre, the Earth is layered like an onion, with the lightest material on the outside and the most dense material at the core. And this process of segregation was more or less completed by 3,900 million years ago, just 600 million years after the planet formed. Geophysicists know this because they have been able to date the oldest rocks of the Earth's crust, using measurements of their residual radioactivity; and they know about the layered structure of the planet from studies of earthquake waves, which are bent and distorted by the different layers.

However, no more than the broad outlines of the picture of the Earth's interior can be determined in this way. The pioneering geophysicist Sir Edward Bullard once told me that "determining the structure of the Earth by studying earthquakes is like a blind man trying to determine the structure of a grand piano solely by listening to the sound it makes when pushed down a flight of stairs". And it is true that scientists know more about the composition of distant stars than about the Earth deep below our feet—after all, we can actually see the stars!

But we do at least have the broad outlines of a picture of the Earth's interior. Starting from the surface, we live on a rocky ball with an average radius of 6,372 kilometres, slightly flattened at the poles. The outer skin, or the crust, represents only 0.6 per cent of the volume of the planet. Below the crust, which varies in thickness from 5 to 35 kilometres, there is a sharp boundary called the Mohorovicic Discontinuity, or Moho.

This marks the top of the mantle, a layer which goes down to a depth of 2,900 kilometres and takes up 82 per cent of the volume of the Earth. Near the top, the mantle is partly molten, with a consistency like thick porridge, or slushy, melting ice. This region of weakness, called the asthenosphere, is of great importance because the crust above can move over it, leaving the continents free to wander around the globe (see page 10). On a broader scale, the mantle seems to be made up of three zones, the upper mantle being about 370 kilometres thick and separated by a transition zone about 600 kilometres thick from the lower mantle, which is itself 1,900 kilometres in thickness. ▶

Evolution of the Earth from a cloud of gas and dust to a rocky planet

of the Earth

by John Gribbin

Photo Crown © British Geological Survey, Geological Museum, London

▶ Below the mantle lies the core—an outer core 2,100 kilometres thick and the inner core itself, with a radius of just 1,370 kilometres, at the centre of the Earth. The outer core is the region of liquid iron, where the Earth's magnetic field is generated.

Venus and Mars are rocky planets like the Earth and formed in much the same way. But our planet is covered by oceans of water, whereas Mars is a cold, dry planet with a thin atmosphere and Venus has a superdense atmosphere covering a baking hot surface. These differences seem to be a direct result of the differences in the distance of the planets from the Sun.

All three planets, astronomers and geophysicists now believe, had no atmosphere immediately after they cooled. Any gases that were present as they formed were driven off by the heat of the Sun. Simple physics tells us the temperature of the surface of each of the three rocky balls, at their different distances from the Sun, once the Sun had settled down to a steady brightness. For Venus, the stable temperature, where incoming heat from the Sun is exactly balanced by outgoing radiation, is 87 degrees Centigrade, and for Mars the figure is -30 degrees Centigrade. These figures, remember, are for *airless* planets. ▶

Vital statistics

Source: *National Geographic Society*, Washington, D.C.

THE EARTH

Weight:	5,973,502,000,000,000,000,000 tonnes
Circumference at the Equator:	40,075 km
Area:	510,074,600 km²
Land:	148,940,540 km²
Water:	391,134,060 km²

THE CONTINENTS

	Area (km²)	▲ Highest point (metres)	▽ Lowest point (metres)	Population
Asia	43,998,920	1 Everest 8,848	1 Dead Sea -396	2,048,898,000
Africa	29,800,540	2 Kibo (Kilimanjaro) 5,895	2 Lake Assal -156	344,000,000
North America	24,320,100	3 McKinley 6,194	3 Death Valley -86	314,970,000
South America	17,599,050	4 Aconcagua 6,960	4 Valdés Peninsula -40	186,013,000
Europe	9,699,550	5 El'bruz 5,642	5 Caspian Sea -28	637,943,000
Australia	7,687,120	6 Kosciusko 2,228	6 Lake Eyre -16	12,200,000
Antarctica	14,245,000	7 Vinson Massif 5,139	Not known	

MAJOR WATERFALLS ■

		Height (metres)
1	Angel	979
2	Tugela	948
3	Yosemite	739
4	Cuquenán	610
5	Sutherland	580
6	Mardalsfossen	517
7	Ribbon	491
8	King George VI	488
9	Gavarnie	422
10	Victoria	108
11	Iguazú	72
12	Niagara	59

LONGEST RIVERS □

		Length (kilometres)
1	Nile	6,669
2	Amazon	6,436
3	Mississippi-Missouri	5,969
4	Ob'Irtysh	5,567
5	Yangtze	5,471
6	Huang	4,827
7	Congo	4,373
8	Amur	4,344
9	Lena	4,312
10	Mackenzie-Peace	4,240
11	Mekong	4,183
12	Niger	4,183
13	Paraná	4,023
14	Murray-Darling	3,717
15	Volga	3,685

LARGEST LAKES ○

		Area (km²)	Greatest depth (metres)
1	Caspian Sea	371,795	995
2	Superior	82,362	406
3	Victoria	69,485	81
4	Aral Sea	65,527	68
5	Huron	59,570	229
6	Michigan	58,016	282
7	Tanganyika	32,893	1,417
8	Great Bear	31,792	413
9	Baikal	30,510	1,620
10	Nyasa	29,604	678

THE OCEANS

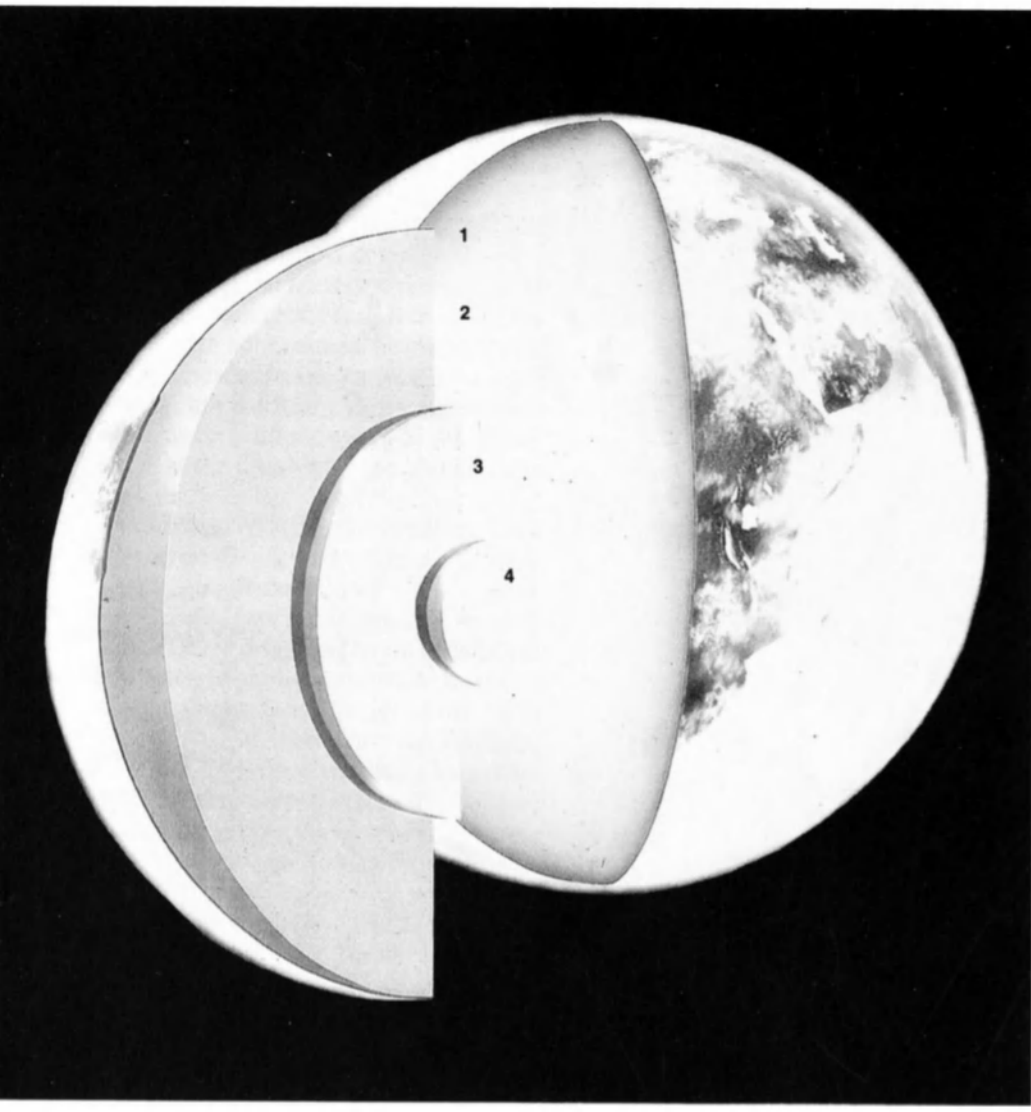
	Area (km²)	Deepest Point (metres)	
Pacific	166,242,517	1 Mariana Trench	11,033
Atlantic	86,557,800	2 Puerto Rico Trench	8,648
Indian	73,427,795	3 Java Trench	7,725
Arctic	13,223,763	4 Eurasia Basin	5,450

MAJOR SEAS ●

		Area (km²)	Average depth (metres)
1	South China Sea	2,974,615	1,464
2	Caribbean Sea	2,515,926	2,575
3	Mediterranean Sea	2,509,969	1,501
4	Bering Sea	2,261,070	1,491
5	Gulf of Mexico	1,507,639	1,615
6	Sea of Okhotsk	1,392,125	973
7	Sea of Japan	1,012,949	1,667
8	Hudson Bay	730,121	93
9	Andaman Sea	564,879	1,118
10	Black Sea	507,899	1,191
11	Red Sea	452,991	538
12	North Sea	427,091	308
13	Baltic Sea	382,025	55

EARTH'S EXTREMES ☆

1. **Rainiest spot:** Mount Waialeale, Hawaii: average annual rainfall: 11,680 mm.
2. **Driest spot:** Atacama Desert, Chile: rainfall barely measurable. (At Calama, no rain has ever been recorded.)
3. **Coldest spot:** Vostok, Antarctica: -88°C (recorded in August 1960).
4. **Hottest spot:** Al'Aziziyah, Libya: 58°C (recorded in September 1922).
5. **Northernmost town:** Ny Alesund, Spitsbergen, Norway.
6. **Southernmost town:** Puerto Williams, Chile.
7. **Highest town:** Aucanquilcha, Chile: 5,334 m
8. **Lowest town:** Villages along the Dead Sea: -396 m
9. **Largest gorge:** Grand Canyon, Colorado River, Arizona: 349 km long, 6 to 21 km wide, 1.6 km deep.
10. **Deepest gorge:** Hells Canyon, Snake River, Idaho: 2,408 m deep.
11. **Strongest surface wind:** 372 km/h (recorded in 1934).
12. **Greatest tides:** Bay of Fundy, Nova Scotia: 16 m
13. **Biggest meteor crater:** New Quebec, Canada: 3 km wide.



Drawing © Geological Museum, London

1. crust granite (continents) basalt (oceans) **2. mantle** peridotite (and denser forms) **3. outer core** iron (liquid) **4. inner core** iron (solid)

Inside the Earth

The Earth's interior has a layered structure. The outermost layer is the *crust;* beneath this is the *mantle;* and in the centre is the *core.* Temperatures and pressures inside the Earth are very high—at the core the temperature is thought to be about 3,500 degrees Centigrade and the pressure nearly 3,750 tonnes per square centimetre.

The Crust: **In relation to the Earth as a whole, the crust is as thin as a postage stamp stuck on a football. It consists of a thin skin of rock which is less dense than the underlying mantle from which it has been derived by complex processes over many millions of years. There are two kinds of crust: *continental crust,* which makes up the continents, and *oceanic crust,* which forms the ocean floors. Continental crust is lighter in weight and much thicker than oceanic crust. It is also very much older—parts of the continental crust are over 3,500 million years old, whereas oceanic crust is nowhere more than 200 million years old.**

The Mohorovicic Discontinuity: **The sharp boundary that marks the junction between the crust and the mantle.**

The Asthenosphere: **This is a hotter, weaker, partly molten section of the top of the upper mantle with a consistency like thick porridge. It is of great importance because it enables the rigid plates of the crust above to move about.**

The Upper Mantle: **scientists believe that the upper mantle consists of dense, dark-coloured rocks, probably peridotite and perhaps also dunite and eclogite, composed of iron and magnesium-rich silicate minerals. Fragments of these rocks are found in volcanoes fed by magma (molten rock) that originates in the mantle.**

The Transition Zone: **In this region, where the upper mantle grades into the lower mantle, higher pressures force the minerals to change their structure.**

The Lower Mantle: **The minerals composing the lower mantle are probably simple oxides with very compact structures produced by high pressures.**

The Core: **Almost twice as dense as the mantle, the core is probably composed of iron with some dissolved sulphur and silicon. The Earth's magnetic field is generated in the *outer core,* which is molten. The *inner core* is thought to be solid.**

▶ On each planet an atmosphere began to form when carbon dioxide and water vapour were produced by volcanic activity (it may seem surprising, but one of the main things that emerges from the fiery furnace of a volcano is water vapour). Although 87 degrees Centigrade is still below the boiling point of water, the temperature on Venus was already high enough for a great deal of water vapour from volcanic outgassing to stay in the atmosphere with carbon dioxide.

Both water vapour and carbon dioxide are very efficient at trapping infra-red radiation—the process is called the "greenhouse effect". So less heat could escape from the planet into space and as a result its temperature quickly rose above the boiling point of water, and then still higher as still more water vapour joined the atmosphere. From then on, all production of volcanic gases thickened the atmosphere and strengthened this greenhouse effect. On Mars the opposite happened. Water may have flowed briefly on the planet, but it soon froze. Venus is a hot desert; Mars is a cold desert. But Earth is different.

On our planet the temperature was high enough for liquid water to flow, but not so high that water vapour could cause a runaway greenhouse effect. Quite the reverse—the warm waters of the young oceans dissolved carbon dioxide out of the air, leaving a much thinner atmosphere than on Venus, while white clouds in the sky reflected away some of the incoming solar heat and let the planet cool. It is no coincidence, astronomers believe, that the mass of all the carbon dioxide in the atmosphere of Venus today is roughly the same as the mass of carbon dioxide locked up in carbonate rocks, such as limestone, laid down from the oceans around the Earth.

If our Sun had been a little warmer, Earth too might have been a superhot desert with a thick, carbon dioxide atmosphere—but if that were so, then Mars would be warm enough for water to flow and life to flourish. Or suppose the Sun were a little cooler; our Earth might have ended up like Mars—but Venus could have become a pleasant planet of oceans and cloudy blue skies. If you are not fussy about exactly which planet you settle on, the implication seems to be that an Earth-like planet is an almost inevitable counterpart of every Sun-like star.

In the case of our Solar System, it just happens to have been the third planet out from the Sun that was, by about 3,500 million years ago, already in possession of oceans of water, continents, a carbon dioxide atmosphere and a comfortable temperature. The scene was set for the emergence of life, and for life itself to begin to change the environment of the planet—but that is another story.

What of the future? Our Sun has existed in a more or less steady state for 4,000 million years, keeping hot as it burns hydrogen fuel into helium in its interior. Eventually the supply of hydrogen will be exhausted. When it is, the inner part of the Sun will collapse slightly and become still hotter as helium is fused by nuclear reactions into carbon. This greater internal heat will cause the outer layers of the Sun to expand and it will become a red giant star, engulfing the inner planets and burning them to cinders. But there is no need to panic. Our Sun is only halfway through its life-cycle, scarcely into middle-age, and "eventually", in this case, means not for another 4,000 million years or more. The fate of mankind lies in its own hands, not in the stars. ■

JOHN GRIBBIN, *British astrophysicist and science writer, former member of the Science Policy Research Unit of the University of Sussex, England, is physics consultant to the magazine* New Scientist. *He has written many books on astronomy, geophysics and climatic change, as well as two novels, and in 1974 he received the United Kingdom's premier science-writing award. His books on astrophysics include* White Holes *(1977),* Timewarps *(1979),* Genesis: The Origins of Man and the Universe *(1981), and* Spacewarps *(1983).*

Our place in the Solar System

Sun
A nuclear furnace that converts hydrogen into helium, releasing an enormous amount of energy. Central star of the Solar System, making up 99 per cent of its mass. Mean surface temperature: 5,500 degrees Centigrade. Core temperature: 17 million degrees Centigrade. Diameter: 1.39 million kilometres. Distance from Earth: 150 million kilometres.

Mercury
Dense, probably partly metallic. May have a thin atmosphere. Average midday temperature: 350 degrees Centigrade. Diameter: 4,840 kilometres. Distance from Sun: 57.9 million kilometres.

Venus
Similar in composition to Earth. Shrouded in a dense atmosphere of carbon dioxide. Surface temperature: 300 degrees Centigrade. Diameter: 12,104 kilometres. Distance from Sun: 108.2 million kilometres.

Earth
Silicate layers surround dense metallic core. Water, and an atmosphere of nitrogen and oxygen, support life. Surface temperature: Between 60 degrees Centigrade and -90 degrees Centigrade. Diameter: 12,756 kilometres. Distance from Sun: 150 million kilometres.

Mars
Surface has Moon-like craters but also such Earth-like features as canyons and volcanoes. Atmosphere is carbon dioxide with a little nitrogen and water. No evidence of life. Surface temperature: (?) 20 degrees Centigrade at Equator. Diameter: 6,760 kilometres. Distance from Sun: 227.9 million kilometres.

Asteroids
Small bodies revolving in paths between Mars and Jupiter. Mostly less than one kilometre across. Mean distance from Sun: 414.4 million kilometres.

Jupiter
Giant frozen planet enveloped in a thick atmosphere of hydrogen and helium. Strong energy source. Diameter: 142,700 kilometres. Distance from Sun: 778.3 million kilometres.

Saturn
Least dense of planets. Mainly hydrogen and helium. Orbited by ice-covered fragments (rings). Diameter: 120,800 kilometres. Distance from Sun: 1,427 million kilometres.

Uranus
Probably ice with some solid ammonia, hydrogen and helium. Owes its green appearance to a methane-rich atmosphere. Diameter: 47,600 kilometres. Distance from Sun: 2,869 million kilometres.

Neptune
Probably frozen methane, water and ammonia. Diameter: 44,400 kilometres. Distance from Sun: 4,498 million kilometres.

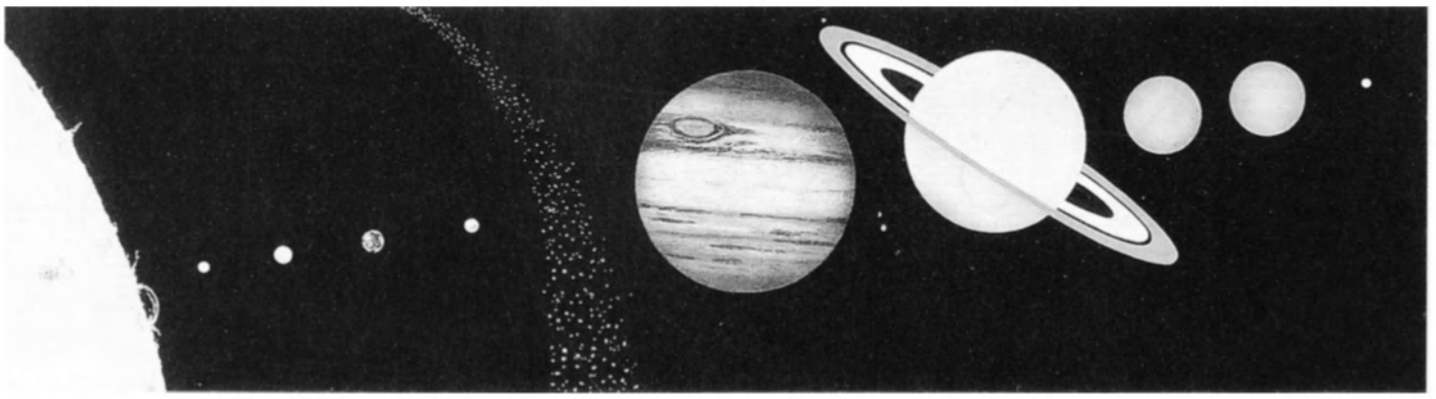
Pluto
Most distant planet yet discovered. Composition unknown. Diameter: (?) 3,000 kilometres. Distance from Sun: 5,900 million kilometres.

The Moon
Its composition shows small but significant differences from that of Earth. Analysis of Moon rocks reveals a far greater proportion of titanium, chromium and zirconium than is found in the Earth's crust, suggesting that the Moon formed separately—probably by an agglomeration of pre-existing solid particles. The surface is marked by countless craters formed by falling meteorites. Bright areas (uplands) represent primeval crust. Dark areas are basins formed 3,600 million years ago by impact and flooded by lava eruptions.

Meteorites
Stony and metallic debris, seared by heat, that falls to the Earth from outer space. They are probably fragments of colliding asteroids. They range in composition from iron-magnesium silicate rock to nickel-iron. They have a maximum age about the same as that of the Earth.

A speck in space

The Earth and the Solar System are extremely small in relation to distances in space. These are measured in light-years—one light-year is the distance light travels in one year—about 10 million million kilometres.
The nearest of the 100,000 million stars in our Galaxy is four light-years away, and the Galaxy itself is 80,000 light-years across. Yet it is only one of millions of galaxies in the Universe.
The Solar System consists of the Sun and the material revolving around it—planets, moons, asteroids, comets, meteorites, dust and gas. Most of this material circles the Sun in the same direction and in the same plane.



Sun Mercury Venus Earth Mars Asteroids Jupiter Saturn Uranus Neptune Pluto

Photo © Geological Museum, London

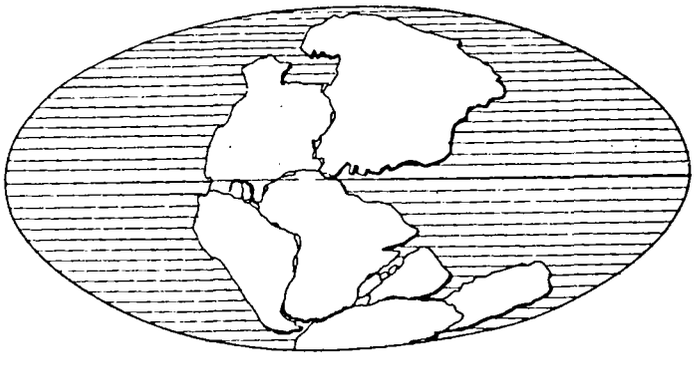
Wandering

Maps © Oxford University Press, Oxford

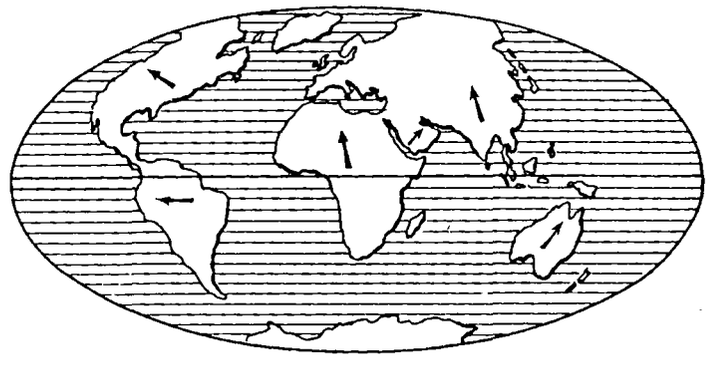
ANYONE who has looked at a world map must have noticed how snugly the coastlines of Africa and the Americas could be made to fit together, if the intervening ocean were removed. Modern geophysics has established that all of the Earth's landmasses were indeed joined together in one supercontinent, Pangaea, hundreds of millions of years ago, and that this supercontinent was broken apart, with the land masses drifting to their present positions on the globe.

This idea took many years to become established. Speculations about the fit of the continents go back to Francis Bacon (1561-1626), but the acknowledged "father" of the idea of continental drift was the German astronomer and meteorologist Alfred Wegener, who published the first comprehensive statement of the theory in 1912. Wegener thought that the continents might move through the thinner crust of the ocean floor, like icebergs ploughing through the sea, and he gathered a wealth of evidence showing how well the continents could be fitted together like some global jigsaw puzzle. But the idea of continents moving through the rocks of the sea floor did not seem feasible, and found little favour until the 1950s, when the development of new geological techniques provided conclusive evidence that the continents do move.

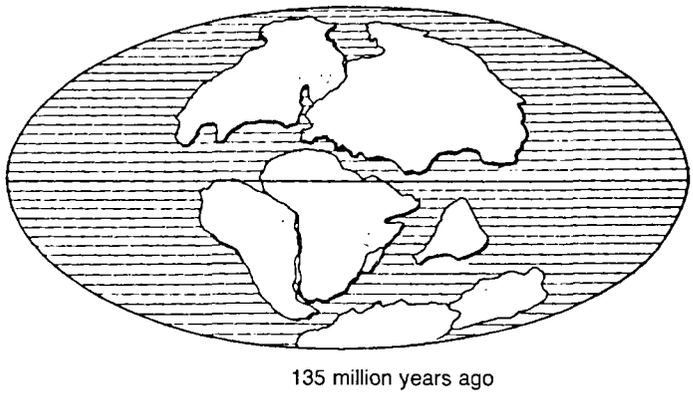
The key evidence came from magnetic studies of the ocean floors. These showed that the crust of the Atlantic Ocean floor is arranged symmetrically on either side of a great ridge of volcanic activity which runs roughly down the centre of the ocean bed. The interpretation of this discovery is that new oceanic crust is being created at the mid-ocean ridge, where it wells up through a crack in the Earth's crust and is pushing out on either side, steadily widening the Atlantic.



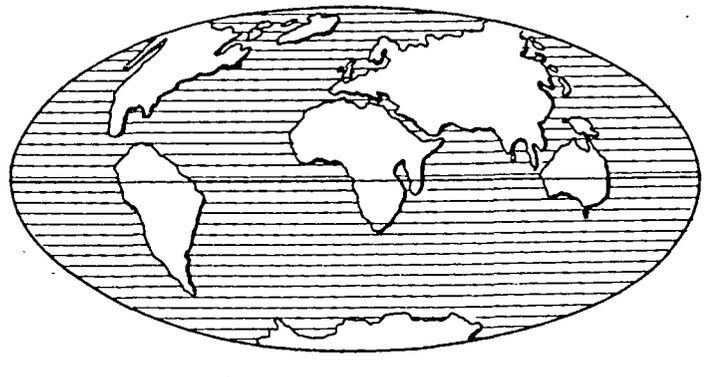
200 million years ago



Present



135 million years ago



In 50 million years' time

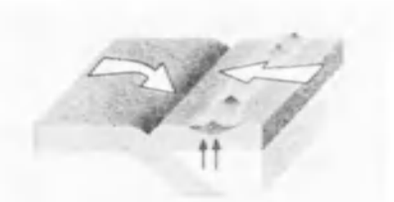
continents

In other parts of the world the reverse happens. The North Pacific, for example, has no oceanic ridge, but there is a deep trench running down the west of the ocean floor, next to the Eurasian landmass. There the thin crust of the ocean floor is being pushed under the continent, back down into the mantle where it melts and is ultimately recycled. The net effect is that there is no change in the surface area of the Earth—spreading in the Atlantic and at other sites is balanced by contraction of the Pacific. A piece of the Earth's crust that is bounded by spreading ridges and subduction zones is called a "plate", which gives the concept of continental drift its modern name, "plate tectonics". In some places, two pieces of crust—two plates—rub side by side, with no net creation or destruction of sea floor. This happens today along the notorious San Andreas fault in California.

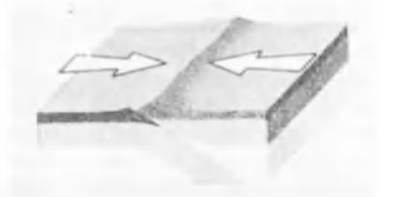
The whole process of break-up and re-arrangement of the continents may have happened several times in the Earth's history, and is responsible for building mountain ranges, where continents collide. India, moving northward into Eurasia, has forced up the Himalayas, which are still growing. By contrast, the line of the Red Sea marks a new (by geological standards) crack in the Earth's crust, a spreading ridge which is splitting Africa off from Arabia, and which may eventually cause this narrow sea to expand into an ocean as large as the Atlantic is today.

Overwhelming evidence for the reality of continental drift, or plate tectonics, was collected during the 1960s and 1970s. But the "icing on the cake" has been provided only in the past few years. Using laser beams bounced off artificial satellites in orbit around the Earth, it is now possible to measure directly the steady widening of the Atlantic, calculated at a couple of centimetres every year. ■

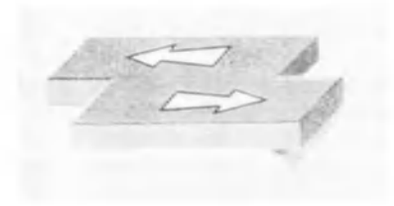
Ocean spreading ridge. Plates are separating; molten rock rises, adding new material to each plate.



Ocean subduction zone. One plate underthrusts another. The edge of one plate is pushed down into the mantle where it melts and is recycled. Some of the molten rock rises to form an island arc.

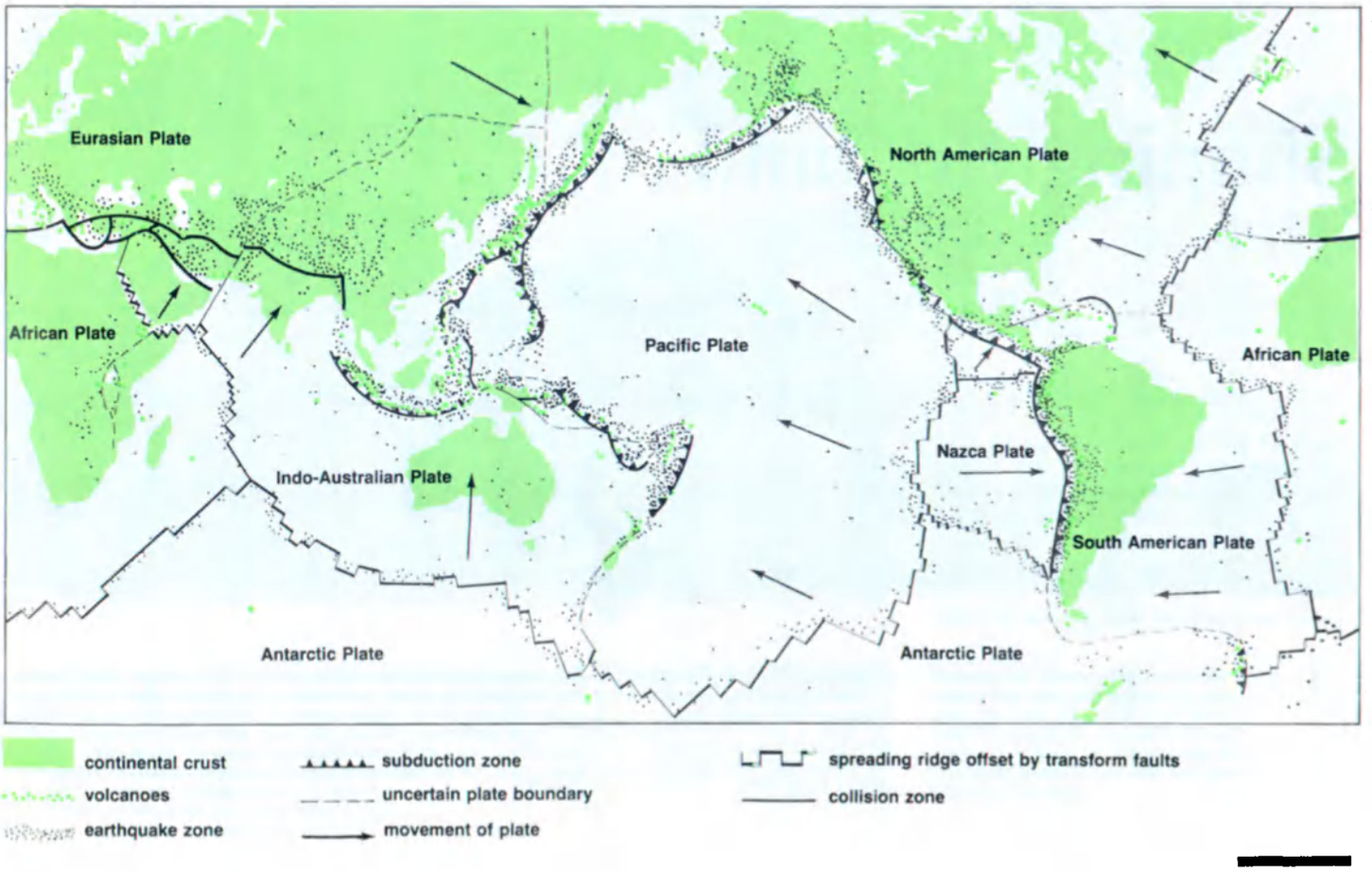


Collision zone. An underthrusting plate rams two continents together, forming a high mountain belt.



Transform fault. Two plates slide past one another with no addition or destruction of plate material.

Illustration © *The Sunday Times* with the Geological Museum, London



Map © Geological Museum, London

Rocks around the clock

The concept of geological time

GEOLOGY is the science which deals with the condition and the structure of the Earth and the evidence afforded of ancient forms of life. It includes the description of landforms, but it is much more concerned with the processes and forces responsible for the landscape we see today.

These processes generally operate extremely slowly. Huge periods of time are involved in the crumpling of the Earth's crust into mountain ranges, in the wearing down of other mountains into plains, in the advance and retreat of sheet ice and in the relentless movement of vast sections of the crust itself.

The concept of the enormity of geological time is a relatively recent one in Western thought. In AD 1656, James Ussher, Archbishop of Armagh in Northern Ireland, after careful study of the genealogies recorded in the Bible, calculated that the Creation occurred at 8 pm on the 22nd of October of the year 4004 BC, an estimate which was widely accepted even as late as the eighteenth century.

In 1785, however, the Scottish naturalist James Hutton published his *Theory of the Earth* in which he suggested that the natural processes such as mountain building and erosion were so slow that the Earth must have been in existence for many millions of years. His views were generally discounted until the early 1830s, when another Scotsman, the geologist Charles Lyell, gave them his backing in his famous three-volume work *The Principles of Geology,* which laid the foundations for evolutionary biology as well as for an understanding of the development of the Earth.

With the emergence of geology as a science in its own right, people at last became aware of the huge length of time nature took to achieve the changes they recognized as having occurred.

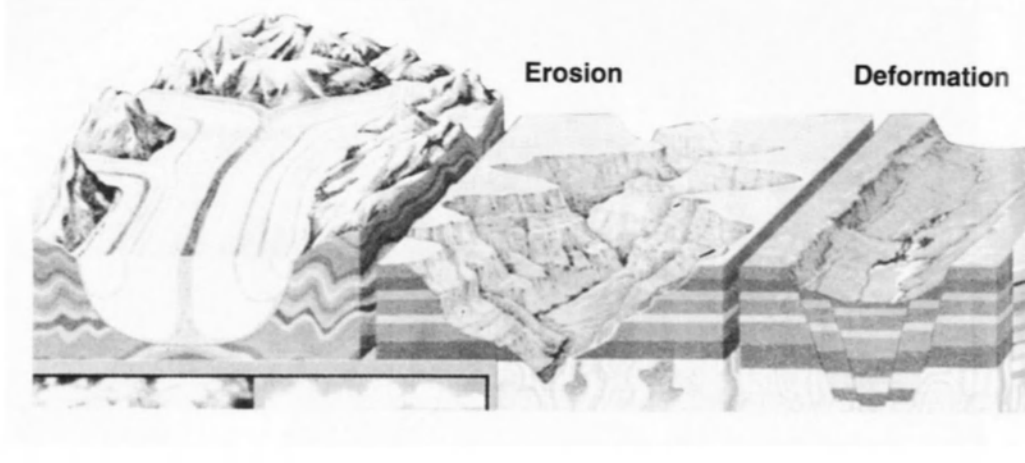
The Earth is a rocky planet and its history, virtually from its origin up to the present, can be elucidated from the study of rocks exposed on its surface or attainable by drilling.

Rocks can be grouped into three major categories: *igneous rocks,* formed from the molten material that rises from the Earth's interior; *metamorphic rocks,* that have been transformed and crystallized by heat and pressure; and *sedimentary rocks,* which have a layered structure and are formed from fragments worn away from existing rocks and deposited elsewhere as sediment (see page 15).

Ancient igneous and metamorphic rocks provide clues as to the origin and early history of the Earth's crust; younger deformed and igneous rock formations help us to understand how mountain chains were formed; and sedimentary rocks, deposited in layers or strata over millions of years, provide the major evidence on which the standard geological time-scale is based.

Sedimentary rocks contain fossils, the remains of once-living organisms. Because living things are continuously changing

Shaping the land



The land surface is shaped by *erosion* and *deformation.* Erosion by water, wind and ice wears away the rocks of the continental crust. Deformation occurs where the crust is unstable, rocks fracture, shear, crush, fold or flow plastically.

U-shaped valleys like this one in Alaska are formed by the gouging action of a glacier moving down a river valley. The moving ice and the rocks it carries abrade and carve out the valley's steep sides.

Canyons are formed when uplift of the land increases the speed and cutting power of a river flowing through a plain. The most spectacular example is the Grand Canyon of the Colorado River, in places over 1.5 km deep (see colour page 20).

Rift valleys, often called *Graben* (the German for "trenches"), are the results of blocks of land sinking between parallel faults. The East African Rift Valley, the world's largest, is nearly 5,000 kilometres long.

through evolution, fossils found in sedimentary rock provide the principal means of establishing the *relative* age of rocks found in different geographical areas. In combination, therefore, stratigraphy (the study of the sequences of rock strata) and palaeontology (the study of fossils in relation to the evolution of the Earth's crust) might be described as the study of "history in layers".

With the development of radiometry in the 1950s, it became possible for scientists to supplement the *relative* age dating obtained from the fossil record with *absolute* age data (that is to say, age in years). The age in years of some types of rock can be calculated from the amounts of radioactive elements and their decay products in the minerals of which the rock is composed. Radioactive isotopes of uranium, potassium and rubidium decay at known rates into stable isotopes of lead, argon and strontium respectively. The decay products begin to accumulate in a mineral after it has crystallized and cooled, thus, as it were, setting a "radioactive clock" running.

Just as "clock" time is divided into hours, minutes and seconds, so geological time (see table page 14) is divided into *Eras, Periods* or *Systems,* and *Epochs* or *Series.*

The first era, known as the Precambrian, covers the span of time from the formation of the Earth's crust, about 4,600 million years ago, until the time, about 570 million years ago, when, for the first time in the history of the Earth, evidence of varied forms of life preserved as fossil remains becomes plentiful. The Precambrian era, which some geologists also divide into two sub-divisions, the Archaeozoic and the Proterozoic, thus comprises nearly 90 per cent of geological time.

Three eras span the period from the end of Precambrian time to the present—the Palaeozoic ("ancient life") era, from 570 million to 225 million years ago, the Mesozoic ("middle life") era, from 225 million to 65 million years ago, and the Cenozoic "modern life") era, from 65 million years ago to the present. Broadly speaking, invertebrates and relatively simple vertebrates, such as fish, amphibians and primitive reptiles were in the ascendant during the Palaeozoic era, the Mesozoic era saw the rise to domination of the larger reptiles, such as the dinosaur, and the Cenozoic, the contemporary era, is the time of the dominance of mammals.

The eras are divided into smaller units called *periods* or *systems.* Most of them are named after geographical regions where rocks containing fossils characteristic of their segments of geological time have been found. Thus the Cambrian period is so called after the ancient name for Wales and the Permian period is named after the ancient Russian kingdom of Permia.

Some periods are named, not after their geographical location, but after the physical characteristics of their rocks. Thus the name of the Cretaceous period is derived from the Latin word for chalk, *creta,* while the Triassic period is so named because, in Germany, rocks of this period are divided into three distinct layers consisting of red sandstones, limestone and shales.

In some cases, both types of nomenclature are used for the same period by geologists in different parts of the world. Thus, two periods which North Americans call the Pennsylvanian period and the Mississippian period (geographical names) are grouped together in Europe as the Carboniferous period (from the coal-bearing nature of its strata).

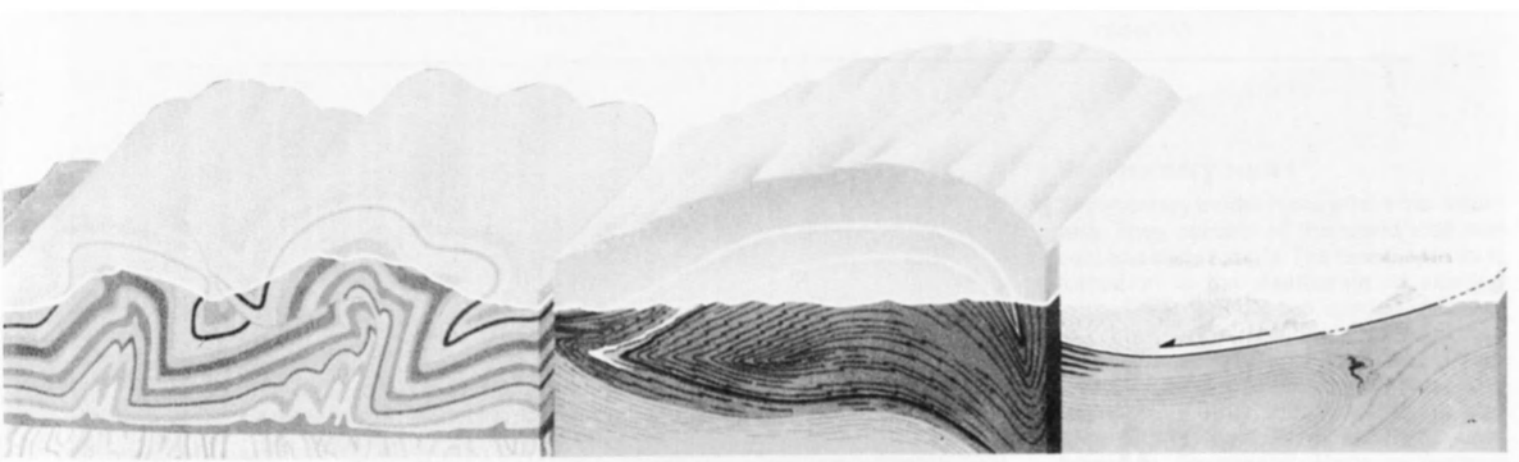
Periods are divided into *epochs* or *series,* which are in turn sub-divided into *ages* or *stages,* and at this point wide divergences appear in the nomenclature used by geologists in different parts of the world.

This is basically because the relationship between geological time and sequences of rock strata has usually been modelled on national or regional traditional thinking, and standards, terminology and classification differ from country to country. Neither the names nor the dates shown, even on a simplified table of geological time such as that published on page 14, will be accepted by all geologists.

The solution of many basic geological problems would, therefore, be greatly facilitated if, through the adoption of common standards and terminology, data from different areas could be made intelligible to geologists the world over. Achieving this aim is one of the major aims of the *International Geological Correlation Programme,* a co-operative undertaking by the International Union of Geological Sciences and Unesco (see page 14).

Of particular importance are projects aimed at progressively refining geological time-scales. Geologists need accurate time-determination methods not only as a basis for research on the evolution of the Earth's crust, but also for identifying and assessing energy and mineral resources.

An understanding of the natural processes which have led to the accumulation of mineral deposits or fossil fuels depends on the geologist's ability to understand the sequence of stages responsible for the formation of deposits and to make accurate correlations between sequences concerned with the formation of similar deposits in widely separated areas. To paraphrase the old saying: "Geological time is money". ■



Drawing © *The Sunday Times,* Geological Museum, London

Detachment, or *décollement,* is a common mechanism of folding in many lesser foothill ranges like the Jura (above). It occurs in flat sedimentary layers alongside rising fold-mountains, in this case, the Alps. As the young fold-mountains rise, they push the sedimentary layers sideways until they are detached from the underlying rocks and are rucked up like a carpet on a slippery floor. The "polish" or lubrication is a soft layer of rock salt or clay underlying the sedimentary layers.

Overfolds form in fold-mountains when rucked-up rock layers topple over. In Scotland, erosion has exposed the underside of such a fold, a wide belt from Aberdeen to Antrim that is upside down.

Nappes are masses of rock that have been driven over younger rocks for long distances until they cover them like a cloth. The Matterhorn (above right) was carved by glaciers out of a nappe of pre-Alpine granite driven over Switzerland from the south.

Geological time scale

Era	Period / System	Epoch / Series	Duration millions of years
CENOZOIC	Quaternary	Holocene	0.01
		Pleistocene	2.5
	Tertiary	Pliocene	4.5
		Miocene	19
		Oligocene	12
		Eocene	16
		Palaeocene	11
MESOZOIC	Cretaceous	Names based on geographical location and vary widely	71
	Jurassic		54
	Triassic		35
PALAEOZOIC	Permian		55
	Carboniferous — Pennsylvanian		45
	Carboniferous — Mississippian		20
	Devonian		50
	Silurian		35
	Ordovician		70
	Cambrian		70
PRECAMBRIAN	Proterozoic or Algonkian	Not divided into periods	4030
	Archaeozoic or Archaean		

A geologist's hammer has been adopted as the "trademark" of the *International Geological Correlation Programme* (IGCP), a major scientific venture, jointly undertaken by Unesco and the International Union of Geological Sciences (IUGS), devoted to the study of the earth's crust and its mineral and energy resources. The Programme involves some 4,000 geologists in more than 110 countries, working on about fifty research projects. It combines the advantages of non-governmental participation and guidance through its scientific partner, the IUGS, with the benefits of governmental support through Unesco. Projects undertaken by the IGCP range from study of geochronology to prospecting for economic mineral deposits and processing of geological data.

A trilogy of rocks

Photo Del Boca © Rapho, Paris

Igneous rocks

Igneous rocks form from molten material (magma) that rises from the Earth's interior. Magma that solidifies before reaching the surface forms *intrusive* rocks like dolerite, gabbro and granite. Magma that solidifies after reaching the surface forms *volcanic* rocks like basalt (the most common), obsidian and pumice. As it cools and crystallizes, the magma's composition changes, producing hundreds of different types of igneous rock from relatively few types of mineral. Rapid cooling may trap minerals formed at higher temperatures.

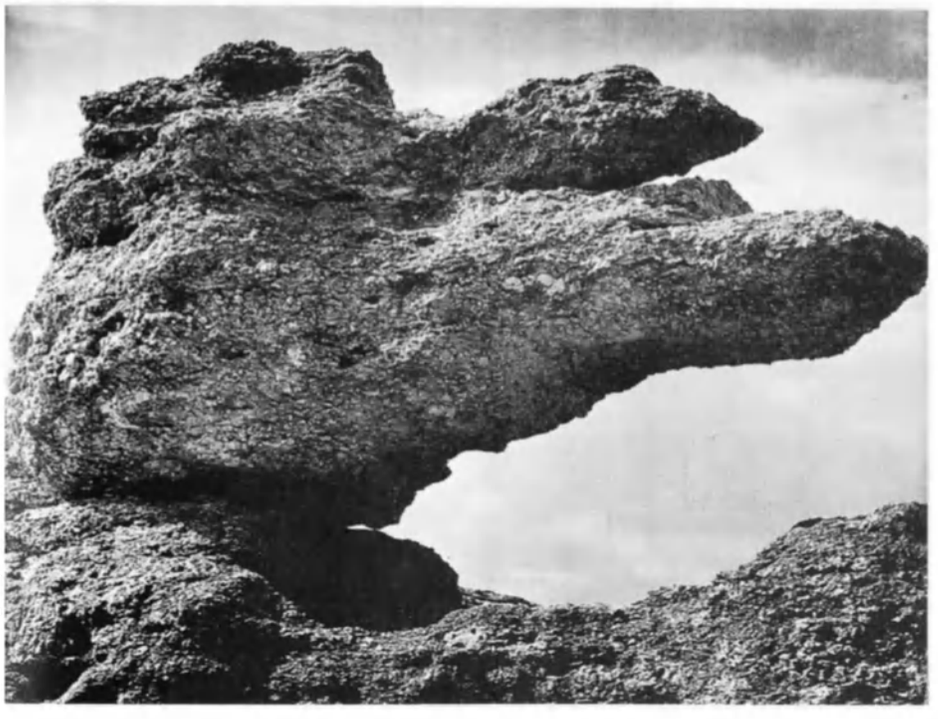


Photo Refot © Rapho, Paris

Metamorphic rocks

Metamorphic rocks are rocks that have been transformed *(metamorphosed)* and crystallized by heat and pressure. In this process, the minerals of the original rock either reform into larger crystals or react together to form new minerals. The rocks produced have a layered texture called *foliation,* familiar to us in slate. Metamorphism occurs in two types of situation: (i) around plumes of molten rock that have risen in cool rock ("contact metamorphism"); and (ii) in the interiors of fold-mountains where the heat flow is high, and beneath ocean trenches where there are high pressures ("regional metamorphism"). Metamorphic rocks include slate, produced from clays at low temperatures and pressures; schist and gneiss, formed at higher temperatures and pressures; and marble, formed from sandstone.

Photo Sibrava, Unesco

Sedimentary rocks

Sedimentary rocks have a layered structure. They contain all the world's oil and coal and all its fossils. The first step in their formation is the weathering of existing rock. The products are carried away as fragments or in solution and deposited elsewhere as layers of *sediment.* These layers, subjected to pressure or cemented together by other minerals, harden into sedimentary rock. There are three main types: (i) *Fragmental.* Made of pebbles (breccia, conglomerates), sand (grits, sandstones, siltstones), or mud (clays, mudstones, shales). (ii) *Organic.* Consisting mainly of the fossil remains of plants and animals (coal, fossil-bearing limestones). (iii) *Chemically formed* by precipitation from salt water or hot springs (rock salt, gypsum, ironstone, some limestones and siliceous cherts).

Drilling into the unknown

by Yevgeni Kozlovski

THE structure of the Earth reflects the long history of its evolution. By reconstructing this history scientists hope to find the key to such processes as the formation of the Earth's crust, volcanism, and the upheavals, subsidences and foldings which led to the development, on the Earth's surface and in its sub-stratum, of conditions which favoured the formation, accumulation and preservation of useful minerals.

In the Soviet Union, study of the complex physical and physico-chemical processes which take place within the Earth's hard crust and the upper layers of the mantle is undertaken within the framework of a vast, integrated programme for the exploration of the "basement" of the country using geological, geophysical and geochemical methods as well as deep and very deep drilling.

The particularity of this programme is that it focuses on the study of the Earth's crust within the limits of the continental zone where most of the planet's useful minerals are concentrated. Geophysical explorations are being conducted along the system of profiles traversing the entire territory of the USSR, and deep and very deep drilling is being undertaken at their points of intersection.

In this way it has been possible to explore the Mohorovicic Discontinuity (the boundary between the Earth's crust and the mantle) and to obtain new data on the structure and physical properties of the upper man-

tle, to identify zones where important fractures occur in the Earth's crust and determine their extent, and to pinpoint the boundaries and structure in depth of major tectonic elements which may be the site of concentrations of mineral ores, oil or gas.

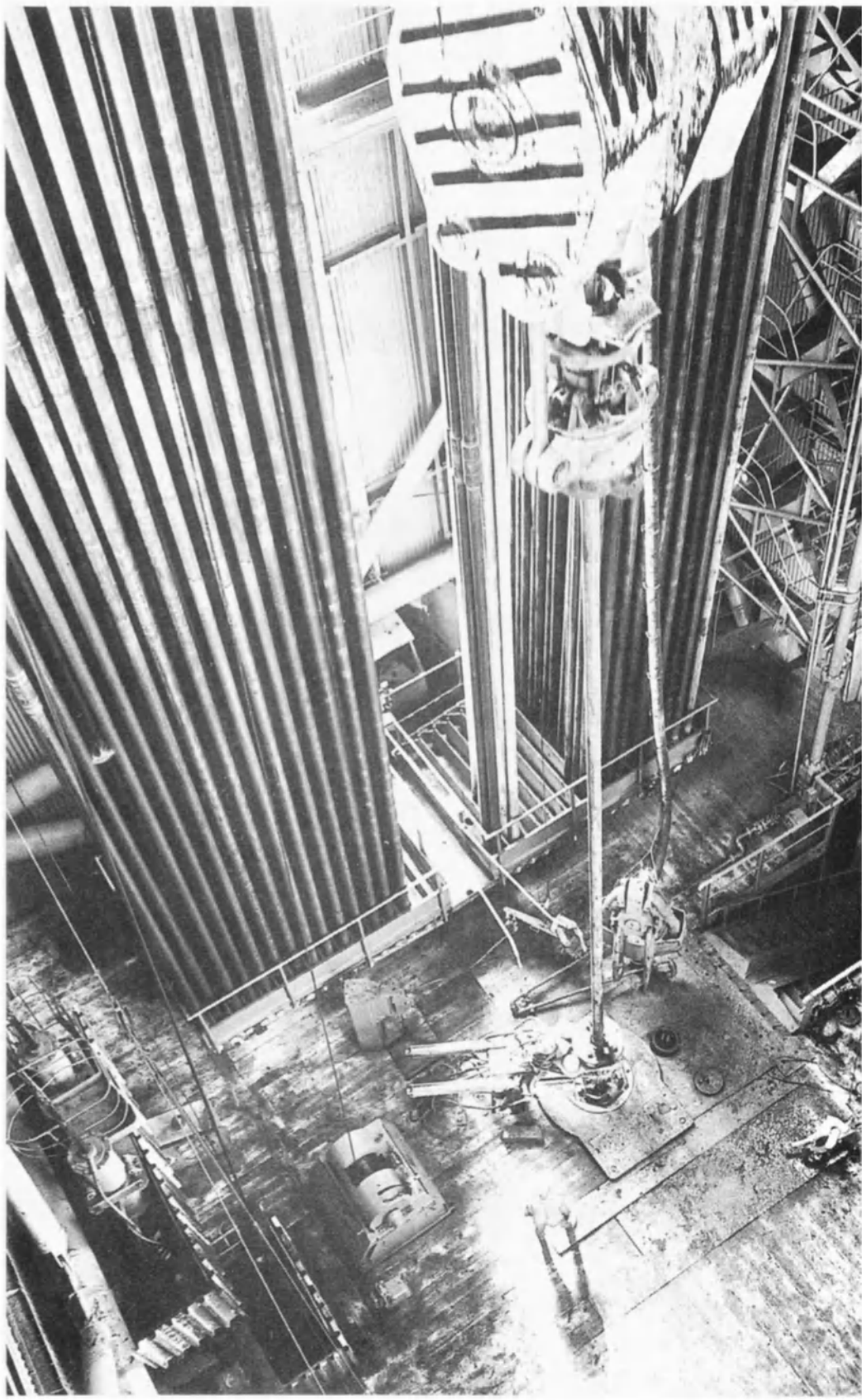
At the heart of the programme is the exploration of the deep structure of the continental crust, on whose layers is imprinted, as on the pages of a book, the whole story of its formation. The first drilling was made in the Kola Peninsula, on the fringe of the Baltic Shield, which is composed of ancient crystalline rock dating back to Precambrian time. The Kola drilling has thrown some new light on the evolution and structure of the early continental crust of the Earth as a whole, since similar formations are widely distributed in other parts of the globe—in India, North America, South Africa, Western Australia, Antarctica and Greenland. Very deep drilling explorations being carried out in the USA, Canada and the Federal Republic of Germany are also contributing to our knowledge of the deep horizons of the Earth in areas potentially rich in mineral raw materials.

The direct observations made possible by these drillings have provided the foundations of the first factually-based model of the continental crust and have led to a revision of earlier notions about the evolution and structure of the Earth's depths.

The Kola drillings have resulted in a series of unexpected and very interesting discoveries.

One of our objectives was to bore through the so-called granitic layer (the upper part of the consolidated crust) to reach a basaltic layer whose existence had been deduced from geophysical data. Geophysicists had observed sharp variations in the speed of seismic waves at great depths, and, since these waves travel faster through granite than through basalt, these variations were thought to indicate a transition in the Earth's crust from a granitic to a basaltic layer. But this was no more than conjecture because, unlike the granitic layer, identified with the Archaean granitoid gneiss which is widely distributed over the surface of the continents, the basaltic layer does not emerge on the surface.

The Kola drilling was the first ever to bore through the line where the seismic waves undergo a sharp change of speed. But contrary to expectations, no basaltic layer ▶



The Kola Peninsula in the far north of the USSR is the site of the first very deep drilling made as part of an ambitious programme aimed at exploring the deep structure of the continental crust and seeking areas potentially rich in mineral, oil or gas deposits. Left, the drilling rig and the accompanying buildings and workshops which house the industrial and technical services. The drilling rig is clad with corrugated iron sheeting to maintain a constant positive temperature in this bleak Arctic environment.

Right, the new sophisticated and fully automated URALMACH 15000 drilling plant, which incorporates the very latest technology, is capable of drilling down to a depth of 15 kilometres. The derrick is 86 metres high and has a hoisting capacity of 400 tons.

Photos © APN, Moscow

▶ was discovered. It became apparent that the variations in the speed of diffusion of the seismic waves was related, not to a transition from a granitic to a basaltic layer, but to the decompaction of the rock which occurs at great depths.

This phenomenon is due to the fact that, under the effect of the high pressure and temperatures existing at great depths, water is released from the crystalline network of minerals and, because of the enclosed space, exerts pressure on the rock, leading to fissuring and consequently decompaction. It turned out that the decompacted zone had subsisted over a long period.

The discovery of the phenomenon of "hydrogenous decompaction" not only makes it possible to explain the geological character of certain boundary zones which reflect seismic waves at great depths, the nature of hydrothermal fluids, and the mechanism of tectonic deformations, it also radically alters our ideas about the hydrological cycle in continental conditions and of the structure of the underground hydrosphere.

The drilling provided extremely interesting information not only for geologists but also for biologists. It was discovered that the deep horizons which had been thought to be "dead" since the beginning of time had actively participated at some stage in the biological processes which took place in the depths of the Earth.

Isotopic carbon analysis revealed two sources of carbonic gas—the first connected with the mantle and found mainly in Archaean rocks, the second of biogenic origin and found predominantly in Proterozoic rock, in which petrified remains of micro-organisms (micro-fossils) estimated to be thousands of millions of years old, were also found.

This was not an isolated discovery. Seventeen species of micro-organisms were found, bearing witness to an extensive development of biogenic processes on our planet in earliest times. Thus biological life started on Earth much earlier than had previously been estimated.

Data supplied by direct measurement of temperatures at great depths have obliged us to revise our concepts regarding present and geohistorical variations of temperature in the bowels of the Earth. It was previously thought that in regions of slight tectonic activity temperature rise in relation to depth increase was insignificant. However, although it was expected during the Kola drilling that the temperature at a depth of ten kilometres would be about 100 degrees Centigrade, it turned out in fact to be almost double this estimate, at 180 degrees Centigrade. It was established that during the Proterozoic era the geothermic gradient (the temperature increase per 100 metres of depth) was five times higher than it is today.

Study of the thermic regime in the bowels of the Earth also provided an answer to a question that has long preoccupied scientists—what is the contribution of the mantle and of radioactive decay of elements in rocks to the overall heat flow in the interior of the Earth? It was established that the mantle was the chief source of ascending heat.

Finally, the existence of underground water inside the old crystalline massifs at practically all the levels reached was proved for the first time. Inflows of highly mineralized water saturated with bromine, iodine and heavy metals were discovered, as well as gases circulating through the crystalline rocks in the zones of tectonic deformation. At depths of 6.5 to 9.5 kilometres, zones of low temperature hydrothermal mineralization (copper, lead, zinc, nickel, silver), previously considered to be primarily near-surface formations, were discovered.

The large number of mineral associations discovered in the rock strata traversed during the drilling confirms the possibility that mineral deposits may be present in industrially viable accumulations.

We were also led to revise our ideas about the physical state and properties of rocks at great depths. It emerged that rock fissures do not disappear as depth increases.

This journey towards the centre of the Earth—the first to such a great depth (15 kilometres)—was made possible by the employment of radically new types of drilling technology and equipment. This vast undertaking necessitated the creation of a unique type of drilling installation—the URALMACH 15000.

Drilling was effected by the open-shaft (untubed) method. This considerably improved the quality and accuracy of geophysical measurements. The reconnaissance operations were conducted, not with steel tubes, but with extra-strong heat-resistant tubes made from specially-developed light alloys capable of withstanding temperatures of 230 to 250 degrees Centigrade. The specially-designed, highly efficient rock-blasting and turbo-drills were powered by the energy of the drilling liquid pumped into the well. A completely new type of apparatus was built to draw rock samples from great depths intact and preserved in their original orientation.

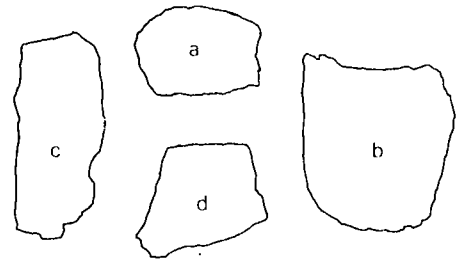
The programme for the study of the subterranean structure in depth provides for exploration throughout the territory of the Soviet Union. Drillings at very great depth are at present being conducted in the Transcaucasus, the Urals, the Krivoï-Rog Basin and the Muruntauski region of Central Asia. A drilling is being set up in the Tiumen district of Western Siberia.

The data provided by them will make it possible, firstly, to assess the oil, gas and ore-bearing potential of deep horizons and, secondly, to elucidate the essential questions relating to the tectonic evolution of the Earth in the light of the continental drift hypothesis. The programme provides for special experimental and theoretical studies concerning the elaboration of a general theory of the evolution and structure of the Earth's tectonosphere. The journey into the Earth's past, undertaken by scientists to decipher its evolution, will continue. ■

YEVGENI KOZLOVSKI, *of the Soviet Union, is head of the interdepartmental council of the USSR State Committee of Science and Technology for the study of the deep layers of the Earth and for very deep drilling. Holder of the Lenin Prize, he is the chief editor of a monograph on deep drilling in the Kola Peninsula, and of the world's first* Encyclopaedia of Mining.

COLOUR PAGES

Opposite page



Top photo: (a) This pebble of volcanic ash, found near Isua in west Greenland, has been shown to have an age of 3,824 million (plus or minus 12 million) years and is the oldest known rock in the world. Other rocks close to this age in the same area are the Amitsoq Gneiss (b) and a banded iron formation (c), whilst the fourth rock (d) is an ancient Antarctic rock.

Bottom left: A stony meteorite from Barwell, England. Meteorites have been dated back to about 4,600 million years.

Bottom right: A rock from the Moon. The oldest rocks brought back from the Moon have been dated at about 4,600 million years.

Photos © British Museum (Natural History) Geological Museum, London

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Above: One of the geological and scenic wonders of the Earth, the Grand Canyon is an immense gorge (in places over 1.5 kilometres deep) cut by the Colorado River into the high plateaux of northwest Arizona, USA. Its rocks, including granite and schist some 4,000 million years old, constitute a unique record of geological events. Over 300 kilometres long, the Canyon is at some points more than 20 kilometres wide.

Photo Alan Keler © Sygma, Paris

Below: Irazú, a volcano in the Cordillera Central, Costa Rica, erupts in an inferno of flame and lava.

Photo Ernst Haas © Magnum, Paris

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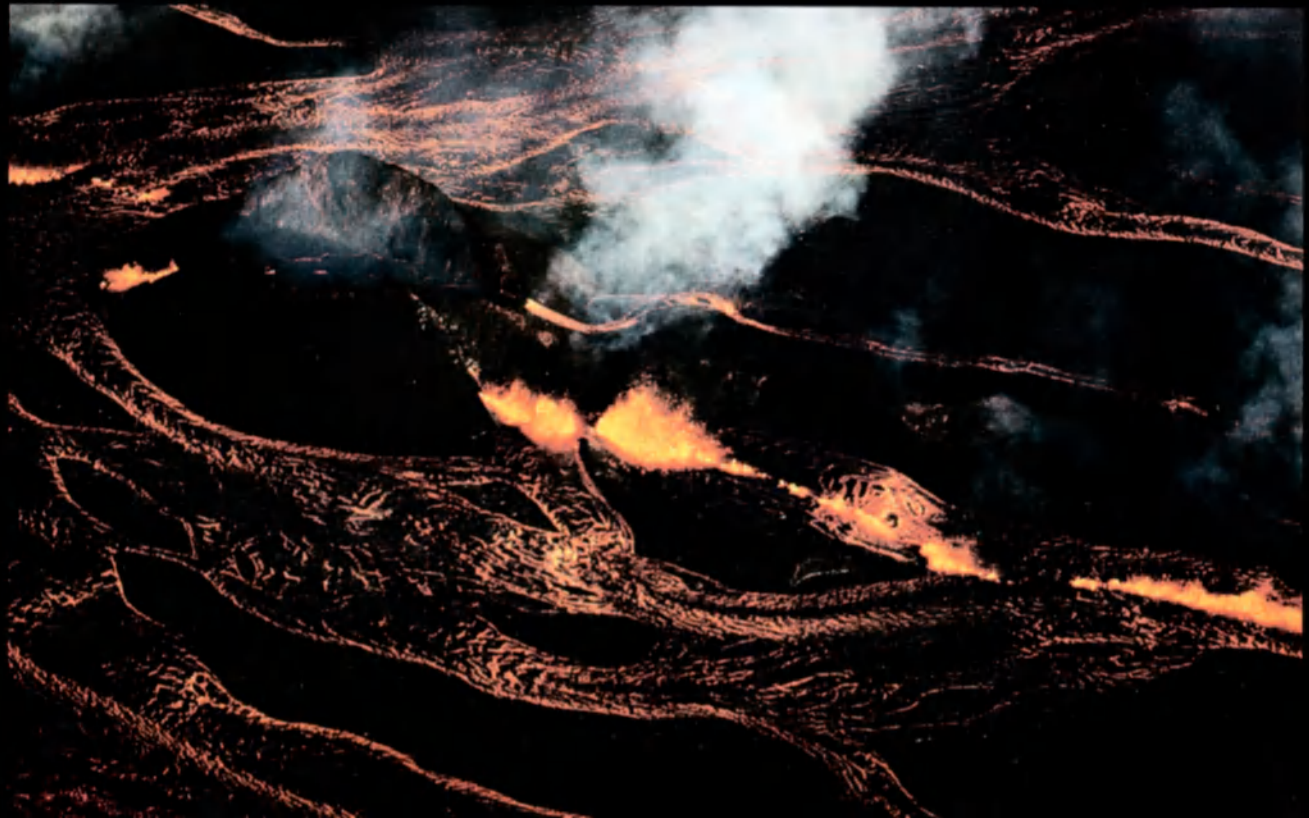
Above: Gases, ash and incandescent, semi-solid lumps of lava are hurled upwards during a volcanic eruption.

Photo Ernst Haas © Magnum, Paris

Below: The Hawaiian volcano Mauna Loa during an eruption in 1984. Rising to 4,169 metres above sea level, Mauna Loa (meaning "long mountain") has a dome 120 kilometres long and 102 kilometres wide. It has averaged one eruption every three and a half years since 1832.

Photo Krafft © Explorer, Paris



The restless Earth

The uncertain art of earthquake prediction

by E.M. Fournier d'Albe

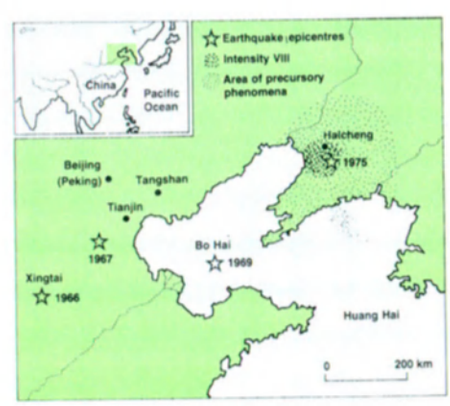
IT is often said that one cannot claim to understand a natural phenomenon unless one can accurately predict its occurrence. If this is true, then the ability to predict earthquakes must be one of the principal goals of the science of seismology.

The scientist who ventures into this field, however, incurs an unusual degree of personal and social responsibility. Prediction of a potentially destructive earthquake may have serious disruptive effects on the social and economic life of a community, whether or not it eventually proves to be correct. Many lives were saved, for example, by the correct prediction of the Haicheng earthquake in China in 1975, but against this must be set many cases of erroneous predictions which have not only damaged the reputations of the scientists concerned but have also had considerable economic and even political consequences.

In the present state of knowledge it is not possible to determine, by observation and calculation, precisely where and when an earthquake will take place. This is because, in order to make a prediction with the required pinpoint accuracy, detailed information is needed on the stress fields and the mechanical properties of the Earth's crust over wide areas and down to depths of several tens of kilometres. Even if it were to become technically possible to obtain such information, the cost of doing so would probably remain prohibitive, and might indeed be greater than that of repairing the damage caused by the earthquake itself.

The few successful predictions that have been made were based on the observation of precursory phenomena of various kinds generated by the same deep-seated process which leads to earthquakes yet not causally related to the earthquakes themselves. Such phenomena might include sudden changes in the level of minor seismic activity, slight deformations of the Earth's surface, changes in magnetic or electrical fields, unusual rise or fall of water levels in wells, changes in the gravity field or abnormal behaviour of animals. However none of these precursory phenomena has yet proved to be a reliable indicator of a forthcoming earthquake. The methods so suc- ▶

Thousands of lives were saved when Chinese experts successfully predicted the Haicheng earthquake of 1975 (see map). Following a severe earthquake at Xingtai, in 1966, scientists noted that the epicentres of subsequent tremors and shocks, including that of the earthquake in the Bo Hai gulf in 1969, seemed to be moving in a north-easterly direction towards the heavily populated Liaoning Province. By June 1974, scientists were predicting that there would be a major earthquake to the north of Bo Hai within one or two years. On 1 February 1975, a series of minor tremors was correctly identified as the foreshock heralding a major shock in the area of the city of Haicheng, and on the following day more than a million people were evacuated to temporary outdoor shelter. Early in the evening of 4 February the main shock (magnitude 7.3) occurred. Although 90 per cent of the houses in the area were damaged or destroyed, there was very little loss of life.



Map © Geological Museum, London

Colour page left

Above: Photo taken in 1965 shows the boiling crater of Surtsey, a volcanic island formed off southern Iceland after a submarine eruption on 14 November 1963. (See picture story page 29.)

Photo Ernst Haas © Magnum, Paris

Below: Air view of the church of the village of San Juan and another edifice partially buried in lava flows from the eruption of Paricutín, in West Central Mexico. One of the Earth's youngest volcanoes, Paricutín began to erupt on 20 February 1943. When the eruption ended in 1952, the peak was 2,800 metres high.

Photo Krafft © Explorer, Paris

cessfully employed at Haicheng failed to predict the terrible Tangshan earthquake in the following year.

New data are constantly being accumulated and there is hope that the accuracy of predictions will gradually improve, although they will of necessity remain probabilistic in nature. They will not state, for instance, that "an earthquake of magnitude X will take place in area Y on a certain date"; rather they will take the form of a statement on the probability of an earthquake of a certain magnitude occurring in a given area during a specified period of time.

So much for the scientific side of the problem. The next question is: What will be the effects of the predicted earthquake, if it actually occurs? How many buildings will be damaged or destroyed, and how many people will be killed, injured or rendered homeless? Will telephone networks continue to function? Will streets be blocked by debris?

In preparing to face an impending earthquake emergency, civil defence services need answers to these questions. They need information on the expected strength of the seismic ground motion and on the vulnerability of buildings and urban lifelines to this motion. They will need to prepare "scenarios" of the probable effects of the predicted earthquake.

For this to be done, seismologists and geologists have first to estimate what will be the intensity of the ground motion caused by the expected earthquake and how this intensity will vary from one part to another of the area round the earthquake focus. This they do on the basis of previous experience and of knowledge of the local characteristics of the soil and sub-soil.

Then an inventory of buildings in the area has to be compiled and an assessment made of how each building is likely to react to the expected ground motion, according to its structural type and to the materials of which it is built. This is where the greatest difficulty lies, since it is almost impossible to predict exactly how any individual building will behave in an earthquake. The best one can do is to base the assessment on information as to how similar buildings have behaved in recent earthquakes elsewhere. Hence the importance of carrying out detailed studies of the damage caused each time an earthquake occurs. Already some extremely valuable information has come from the studies made in Romania and Yugoslavia of the damage caused in those countries by the earthquakes of 1977 and 1979.

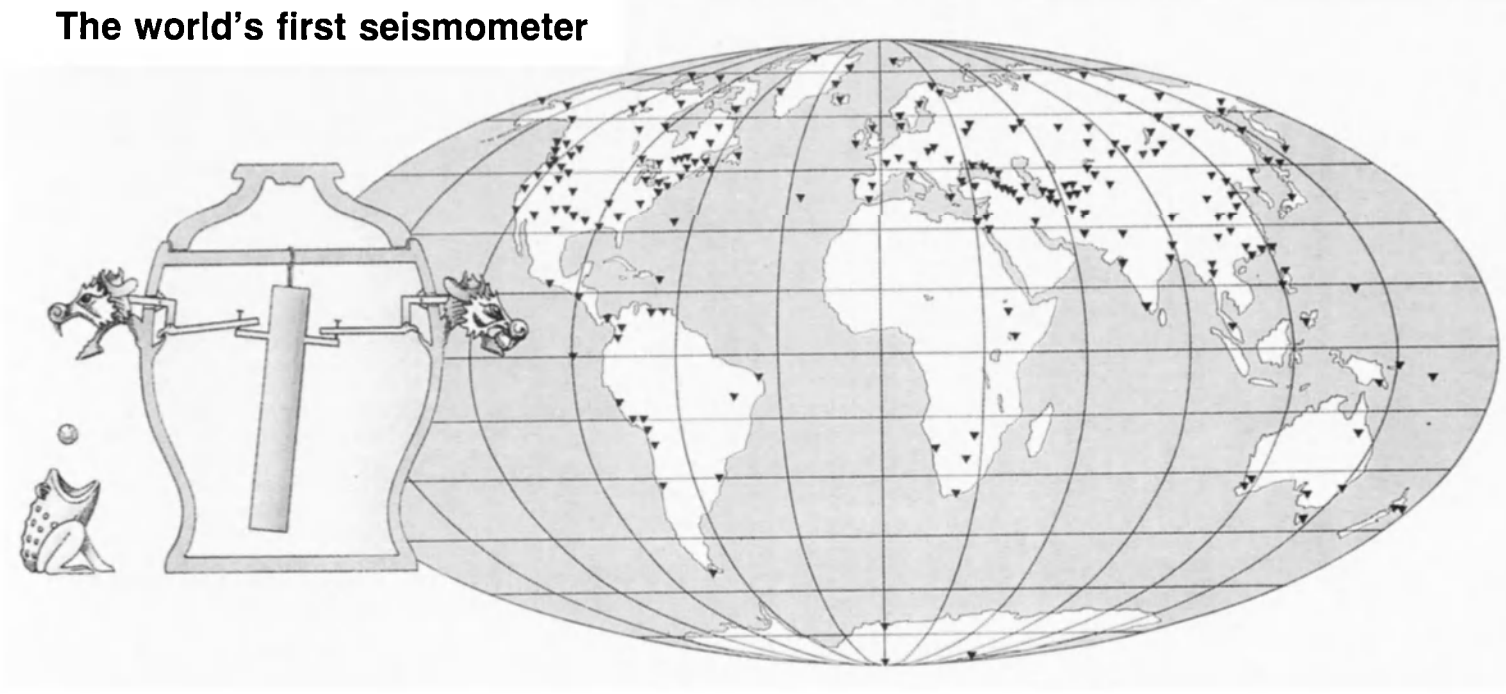
Clearly, all this work takes time and should preferably not be left until an earthquake is impending. For this reason civil defence services in many earthquake-prone countries are already collecting such information and preparing scenarios, so as to be ready to deal more effectively with possible earthquake disasters, whether or not they are predicted in advance.

Earthquake scenarios are invaluable not only for planning the mobilization of rescue teams, medical and fire-fighting services, and the stockpiling of emergency supplies of food and shelter against a possible earthquake, but also for planning the various temporary measures of protection that can be taken in response to a prediction. For instance, inflammable or toxic substances can be moved into safe storage, vulnerable systems in chemical plants can be shut down for a time, water levels in reservoirs can be lowered and schools and theatres can be temporarily closed. In the final stage of an alert, people can be evacuated from their homes or places of work in vulnerable buildings.

Such measures are costly and disruptive of individual and social life. They may be resisted and cannot be prolonged for more than a few days, and they will probably be abandoned after one or more false alarms. They are therefore likely to be applied in response to an earthquake prediction only if the responsible authorities are convinced that the prediction satisfies certain criteria of accuracy and reliability.

As we have seen, scientific predictions are likely to be expressed in terms of probability. Public authorities, on the other

The world's first seismometer



The first known instrument capable of sensing earth motion was invented in AD 132 by the Chinese philosopher Chang Heng. It consisted of a large bronze vessel, some two metres in diameter, around which were spaced eight dragon heads with pivoting jaws in which were held eight balls. Inside the vessel was a pendulum with eight arms each of which was connected to one of the dragon heads. When an earthquake shock caused the pendulum to vibrate, the arm connected to the dragon head facing the direction of the shock caused its jaws to open allowing the ball they held to fall into the open mouth of one of the eight toads positioned around the base of the vessel. The instrument was sensitive enough to detect an earthquake whose epicentre was over 600 kilometres away. It was not until 1856 that a seismograph capable of recording the passage of seismic waves and giving their amplitude, time of onset and direction was installed at the observatory at Vesuvius. Opposite page, a modern reconstruction of Chang Heng's apparatus and, above left, its mode of operation. Since the founding, in the early 1960s, of the Worldwide Standardized Seismograph Network (WWSSN), *seismic observatories with standard equipment and synchronized time-keeping have been established virtually throughout the world. Map above shows distribution of the WWSSN and associated observatories.*

hand, have to make decisions on a "yes or no" basis. It is therefore of crucial importance to develop an effective dialogue between scientists and public authorities. The latter need to acquire, through discussions with the scientists, insight into the reasoning that leads to the formulation of predictions in a particular form. For their part, scientists need to familiarize themselves with the problems faced by public authorities, so that they will understand the responses of the latter to predictions and the reasons behind those responses.

It is essential that any earthquake prediction that is communicated to the public should be accompanied by a verifiable estimate of the probability of occurrence of the predicted event within the specified limits of time and space. If it is to be useful in practice, the prediction must also meet the following criteria:

(a) its *lead time* (the interval between the issue of the prediction and the expected occurrence of the event) should be *longer* than the time required for putting into effect the appropriate protective measures and for mobilizing the resources needed to deal with the emergency;

(b) its *time window* (the duration of the period during which the event is predicted to occur) should be *shorter* than the maximum acceptable duration of protective measures such as the evacuation of buildings, the temporary closure of plants and the mobilization of rescue services.

The above criteria are, of course, very difficult to satisfy given the present state of scientific knowledge, but experience has shown that predictions that fail to meet them can cause severe social and economic disturbance without being of any great use to the community concerned. Earthquake prediction is not only a scientific problem but one which concerns the community as a whole.

The development of techniques of earthquake-resistant design and construction offers the hope that in the course of time death and destruction in earthquakes will become a thing of the past. The phenomena accompanying some volcanic eruptions, however, are of such violence that there are no means of protection against them. The only hope of survival lies in flight from the threatened area. Accurate prediction of eruptions is therefore of vital importance for the safety of people living on or near active volcanoes.

Fortunately, the problem of predicting eruptions is slightly less difficult than that of predicting earthquakes. This is because the possible sites of volcanic eruptions are usually known. It is rare for an eruption to occur anywhere but from an existing volcanic structure, although eruptions do sometimes occur at volcanoes that have been dormant for so long that they are thought to be extinct. By careful geological study it is possible to identify and map the areas around a volcano that have been affected in the past by one or more of the destructive phenomena that accompany eruptions—glowing avalanches, mudflows, lava flows, heavy ash falls, and so on.

A census can be made of the people who live or work in these hazardous areas, together with an inventory of movable property and livestock. Evacuation routes to safe refuge zones can be identified and plans made for rapid evacuation in the event of an eruption. Arrangements can be planned for the emergency shelter and housing of evacuees in the refuge zones. If worked out in detail beforehand, such plans can be instrumental in saving many lives when an eruption occurs.

As in the case of earthquakes, predictions based on the observation of precursory phenomena are necessarily expressed in terms of probabilities of eruption. There will always remain, therefore, the problem of making "yes or no" decisions in situations of uncertainty. The risk of a possible catastrophe has to be weighed against the certainty of the inconvenience, hardship and cost of removing people from their homes, perhaps for periods as long as weeks or months.

Here again it is of crucial importance that ▶

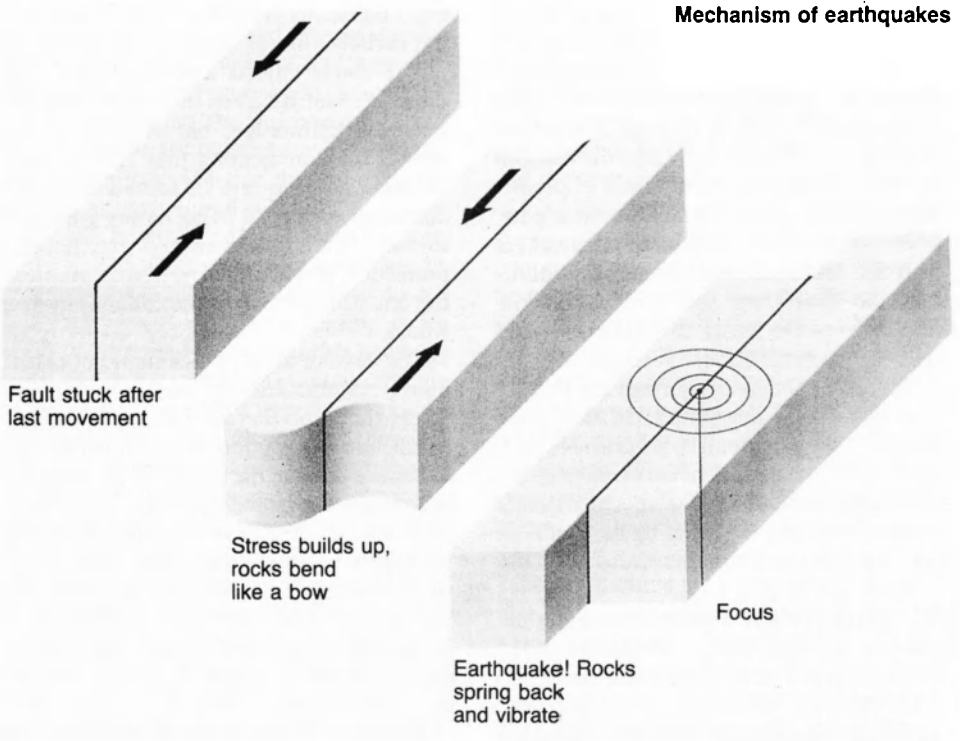
Photos © Geological Museum, London

▶ an effective dialogue be developed between scientists, civil authorities, the news media and the public before any emergency arises. The threat of an imminent earthquake or volcanic eruption is a great revealer of the strengths and weaknesses of any community.

"Success stories" in dealing with such threats are still few, but they do demonstrate that, if scientific predictions are precise and reliable, if the civil authorities are prepared and have the means to take appropriate protective action, and if the public is kept fully informed of the situation and of the action being taken to meet it, the losses inflicted by these violent manifestations of nature can be reduced and may in time become a thing of the past. ■

E.M. FOURNIER D'ALBE, *of the United Kingdom, is a specialist on earthquake risk management. Until 1979 he was head of Unesco's Division of Earth Sciences and was responsible for the initiation and development of the Organization's programme related to natural disasters and their prevention.*

Mechanism of earthquakes



Drawing © *The Sunday Times*-Geological Museum, London

When the Earth shakes

ALTHOUGH some minor earthquakes have been triggered by human activities, such as underground nuclear testing and the construction of reservoirs and dams, the principal cause of all major earthquakes and most minor ones is the fracturing of rocks following the gradual accumulation of stress during geological processes.

The Earth's surface is made up of a series of plates (see page 10) and the severest earthquakes tend to occur at the plate margins, where plates slide past each other as, for example, along the San Andreas "fault" region of California. Diagram above offers a simplified illustration of the mechanism of an earthquake. Rock has a certain elasticity and where adjacent areas of rock are subjected to the push/pull forces of plate movement stress gradually accumulates. When the strain becomes too great, the rock ruptures and tension is released as the rocks on either side of the fault spring back violently. The point at which the rupture originates is called the *focus* and the point on the Earth's surface directly above the focus is called the *epicentre.*

The energy released is emitted in waves which cause the ground to oscillate. It is these seismic waves that are picked up and recorded by seismographs, instruments which enable scientists to pinpoint the epicentre of an earthquake and to measure its magnitude.

Two scales are commonly used to measure the size of an earthquake. The *magnitude* of an earthquake—the total amount of energy released or dissipated—is expressed in terms of the *Richter Scale* and is based on seismograph recordings of the amplitude of seismic waves. To cover the huge size range of earthquakes, the Richter scale of magnitude is logarithmic rather than arithmetic, that is to say, the scale is so arranged that each increase in magnitude of one unit represents a thirty-fold increase in earthquake size. Thus an earthquake of magnitude 8 on the Richter scale is 810,000 times as large as one of magnitude 4.

The *intensity* of an earthquake classifies the degree of shaking and is based on inspection of damage and on information supplied by people involved in the earthquake. The scale most commonly used is called the *Modified Mercalli Intensity Scale* (see below). Since this scale is based purely on *observation* of earthquake effects, the points on the scale are stated in Roman numerals, from I to XII, rather than in ordinary numbers, which might be interpreted as indicating some kind of *measurement.*

Modified Mercalli Intensity Scale

I Not felt by people.
II Felt by people at rest on upper floors of buildings.
III Felt indoors; vibrations like a light truck passing outside. Hanging objects swing.
IV Vibration like passing of heavy truck; windows, dishes and doors rattle.
V Felt outdoors; sleepers wakened and liquids spilt.
VI Felt by all; many frightened and run outdoors; plaster and masonry cracked; furniture moved or overturned; windows, glassware and dishes broken.
VII Difficult to stand up; noticed by drivers of moving vehicles; plaster, loose bricks, tiles, etc. fall; large bells ring; waves on ponds.
VIII Difficult to steer vehicles; fall of stucco and some masonry walls; fall of chimney stacks, towers, monuments; branches broken from trees; cracks to be seen in wet ground.
IX General panic; frame structures cracked and underground pipes broken; conspicuous cracks in ground; sand craters.
X Most masonry and frame structures and foundations destroyed; serious damage to dams and embankments; some bridges destroyed; large landslides.
XI Railway lines badly bent; underground pipes completely out of service.
XII Damage nearly total; lines of sight and level distorted; objects thrown up into the air.

Volcanoes

by Haroun Tazieff

VOLCANISM plays a fundamental role in the story of the Earth. The crust we live on, the water in oceans, rivers and lakes and most of the atmosphere we breathe are derived ultimately from volcanic eruptions. Without volcanism there would be no creation of new oceanic crust through sea-floor spreading, no subduction (the dragging down of older crust into the mantle where it is melted and recycled), no orogenesis (mountain-building) and therefore no erosion and no sedimentation.

Without volcanism the Earth would lack the colossal, continual flow of sulphides, oxides, halogens, hydroxides of all existing metals, emitted in the form of gases at high temperature by fumaroles (volcanic vents) from the thousands of active craters, whether dormant or in eruption, whether submarine or on land, scattered the length of the 100,000 kilometres of the belts that mark the frontiers between the Earth's tectonic plates (see page 10) and the fractures occurring within those plates.

Without the contribution of submarine fumaroles there would be no mineral sulphide deposits; without fumaroles the marine environment, whose chemical make-up made possible the emergence of life and conditioned its evolution, would not have existed; without fumaroles the Earth would have lacked the elements to form the atmosphere whose composition made it possible for life forms emerging from the ocean to colonize the land and then to evolve to give rise to human beings.

Like everyone else at that time, I was unaware of all this when, in 1948, chance brought me face to face for the first time with the strange phenomenon of a volcanic eruption. Like all my fellow geologists of that generation, especially my European colleagues, I had received from my teachers, among whom were some of international renown, a course of instruction in which volcanism was barely mentioned, since, in their view, it represented no more than "a skin disease of the planet".

At all events, I knew practically nothing at all about volcanism when, one day in March 1948, to the north of Lake Kivu in the Belgian Congo (now Zaire), the first eruption I was privileged to see not only opened the eyes of the naive geologist I then was to the magnificence of the spectacle but also to a phenomenon which, because of my lack of knowledge, raised more questions than it provided answers.

In the forty or so years that have passed since then, volcanology, moribund at the close of the Second World War (barely surviving in the United States and in New Zealand, but extinct everywhere else), gradually revived and finally, in parallel with oceanography, came into full blossom. The new knowledge these two disciplines enabled us to garner soon revealed the fundamental role played by volcanism both in the phenomenon of sea-floor spreading and the genesis of life and its evolution over the past 3,000 million years.

More than a third of a century spent in observing eruptions from as close as possible and in measuring everything there was to measure—among other things energy flows (mainly thermal) and the flow of matter (mainly in the form of gases)—has enabled me to establish that, rather than the liquid or lava phase, as most people seem implicitly or explicitly to imagine, it is the gaseous phase that plays the active role in volcanism. Lava is totally passive and, without its eruptive gases, volcanism would simply not exist. Furthermore, eruptions always involve the emission of gas, but not always of lava.

These considerations led me to the conviction that, in order to understand the mechanism of eruptions, it was essential to know the chemical composition and thermodynamic evolution of their gaseous phase. It would seem that the chemical composition of these gases varies from one kind of eruption to another and from one type of magma to another, but in our present state of knowledge it has not been possible to establish a correlation between the chemical variations detected and the variations in activity observed.

It must be admitted that, up to now, only an insignificant amount of data has been acquired on the physico-chemical composition of eruptive gases. By eruptive gases I mean those that have not been subject to much cooling, oxidation by the air or hydration by groundwater, all of which processes transform the gases to a lesser or, more often, a greater extent.

Obviously, to measure the chemical and physical properties of the eruptive gases before they degrade into fumarole gases, it is necessary to get close to the vents from which they are being emitted. This usually demands some physical effort and, at times, a certain amount of courage. What too many volcanologists lack is not courage but a taste for muscular effort. Between the ages of twenty and thirty, some seem to possess it, but I have noticed that, once they have attained a certain academic standing, they usually appear to lose it.

This would not be too serious were it not for the fact that, in addition to the raw data which will continue to be provided by the young and still enthusiastic volcanologists, a *sine qua non* of progress in this field is experience of the actual event of eruption, the complexity of which is matched by its variability. This can only be acquired by direct observation of the phenomenon of eruption in all its successive forms.

The competence of the volcanologist in this respect, like that of a physician, depends both on proper knowledge of important publications and on experience gained through the examination of a maximum number of subjects—patients for the doctor, volcanoes in eruption for the volcanologist.

My first ten years of volcanological research in the field were devoted exclusively to seeking an explanation of the various aspects of the phenomenon of eruption. I soon became convinced that the maturation of dormant magma resulted from the release of the gases formerly dissolved within it. The chemical properties, size and distribution of gas bubbles within the viscous mass, their growth in size either by two or more bubbles joining up or by expansion during their ascension through the magma and of the magma itself, all these factors play their part in the maturation of the magma before the eruption and in its evolution during the eruption itself.

Whether they can be measured or merely observed, when correctly inter-▶

preted the parameters of an eruption enable us more or less to understand the eruptive process and, consequently, sometimes to predict it.

This understanding enabled me, from 1958 on, to answer accurately questions put to me by the administrative or political authorities of a number of cities, provinces, even countries, where a volcano appeared to pose a threat to public safety. Thus I found myself gradually moving from fundamental research to research applied to the forecasting of possible eruptions. Since 1981, when the French Government decided to take an official stand on the mitigation of catastrophic events, my work in volcanology has been limited to this area.

Over nearly thirty years I have found myself in the position of having to answer questions from the authorities in a dozen or so different countries. And if my replies have not once been mistaken, this is because, like a good doctor, I have based my diagnosis on the information available interpreted in the light of my experience. Out of fifteen cases which I recall, I was able to give nine reassuring replies, to confirm the threat of danger three times and, on three occasions, was obliged to admit that I did not know.

Over this period, the questions put to me were seldom in the form "Is there going to be an eruption or not?" Usually I was asked whether there was or was not any danger from an eruption actually taking place. While, under such circumstances, the latter question is clearly the most important, it is also the most difficult one to answer.

It is, in fact, relatively easy to predict an eruption when the volcano in question is being properly watched over by genuine experts with adequate equipment. With the exception of eruptions resulting from a build-up of steam pressure caused by overheating of underground water beneath a blocked vent hole—eruptions which emit no magma or lava, but only steam, some fumarole gases and fragments of the rock blocking the vent—all volcanic eruptions are the result of the ascent to the surface of the globe of a certain volume of magma.

This ascension of magma cannot occur without some movement of the Earth's crust in response to the pressure of the magma; either the crust stretches and becomes deformed, or it fractures. Surface deformations can be detected and measured by such instruments as tiltmeters, extensometers and geodimeters. The opening of fractures, through which magma can infiltrate into the crust and rise to the surface, causes tremors which can be recorded by seismometers.

These geophysical observations and measurements, which can give warning of an eruption, often several months but sometimes only days or hours in advance (depending, among other things, on the depth at which the magma is situated before it begins its ascension), are supplemented by other observations which may help the volcanologist in making a forecast. These include the temperature, composition and pressure of fumarolic gases, and changes in the magnetic field of the Earth's crust. All these indications enable experienced volcanologists to detect a coming eruption and to give a date for its arrival, sometimes with very great precision.

Unfortunately, from the point of view of saving lives, such predictions are of little importance. Magmatic eruptions, whether they be explosive or effusive, never start in disastrous fashion. The first phase of an eruption is *always* (to my knowledge no exception to this rule has ever been observed) relatively moderate, allowing inhabitants time to leave the threatened area.

Evacuation, the only way to protect people from major volcanic risk, is rarely necessary, since it is quite exceptional for an eruption, after its initial phase, to deteriorate into a paroxysmal phase or to become even slightly more dangerous. Out of the average hundred eruptions that occur year after year throughout the world, scarcely one will develop in this way and so justify special precautions.

The major problem that faces the volcanologist is to forecast the evolution of eruption while it is taking place—a task infinitely more difficult than predicting an imminent eruption. Once an eruption has begun, all the mechanical indications—deformation or fracturing of the surface—connected with the rise of the magma through the Earth's crust will have disappeared and the flow of magma will be "fluid", that is, it will no longer have to fracture the rock in the depths or lift the flanks of the volcano to force its way to the surface.

Deprived of these two indicators that are fundamental to the forecasting of a coming eruption (tremors and deformation of the surface), the volcanologist is obliged to establish his diagnosis on the basis of his interpretation of the other physical and chemical indications mentioned above. Correlation of the various factors involved and their interpretation ▶

CONTINUED PAGE 31

Waves of destruction

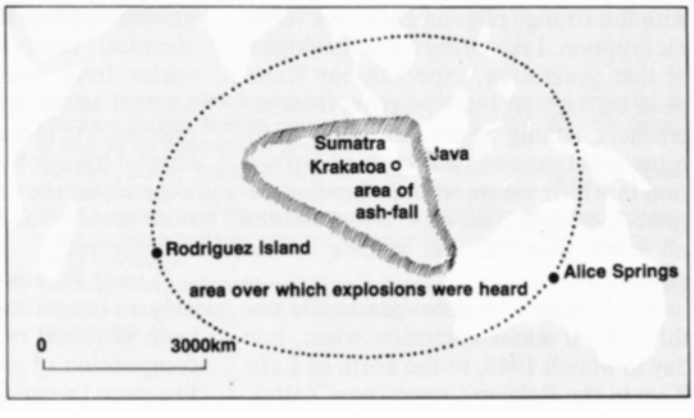
At one o'clock in the afternoon of 26 August 1883 the first of a series of increasingly violent explosions occurred on the volcanic island of Krakatoa, in the Sunda Strait between Java and Sumatra, Indonesia. An hour later, a black cloud of ash rose 27 kilometres into the air above the island.

The eruptions continued, reaching a climax with a tremendous explosion at ten o'clock in the morning of the following day which sent ash billowing 80 kilometres into the air and which was heard in Australia over 4,000 kilometres away. All but a fragment of Krakatoa, the cone of a huge underwater volcano, disappeared beneath the waves.

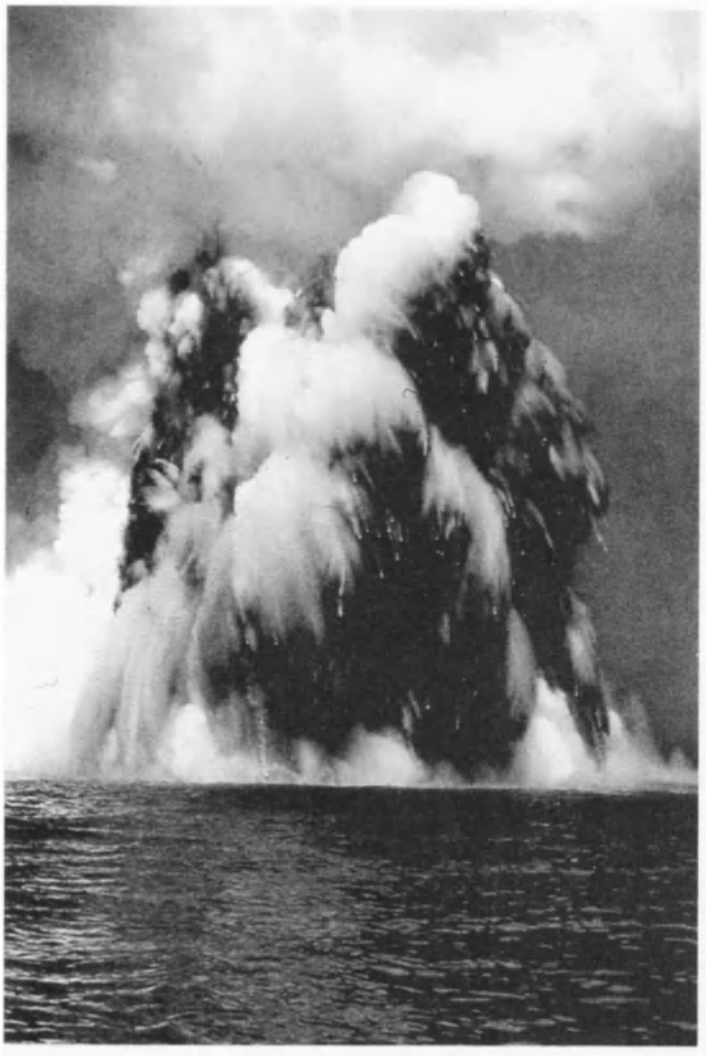
On the neighbouring islands of Lang and Verlaten, volcanic ash and debris lay 60 metres deep. Vivid sunsets caused by fine ash particles in the air were seen as far away as Europe and rafts of pumice (lava filled with gas bubbles) floated on the surrounding ocean for many months.

Worse was to come; the collapse of the volcano triggered a series of tsunamis, or seismic sea waves (often called tidal waves, a misnomer since they have no connection with tides). The biggest wave, which attained a height of some 35 metres, devastated some 300 towns and villages on the shores of Java and Sumatra, taking 36,000 lives.

Almost all tsunamis occur in the Pacific. They are caused by a sudden vertical movement of the sea bed resulting from a submarine volcanic eruption or an earthquake. Following a disastrous tsunami in 1946, a warning system was established covering the entire Pacific Ocean. Tsunami detectors and seismic recording apparatus at seismic observatories around the Pacific sound the alarm whenever a likely event is detected. The information recorded is transmitted to the Honolulu Observatory which is responsible for assessing the risk and issuing warnings if this is considered necessary.

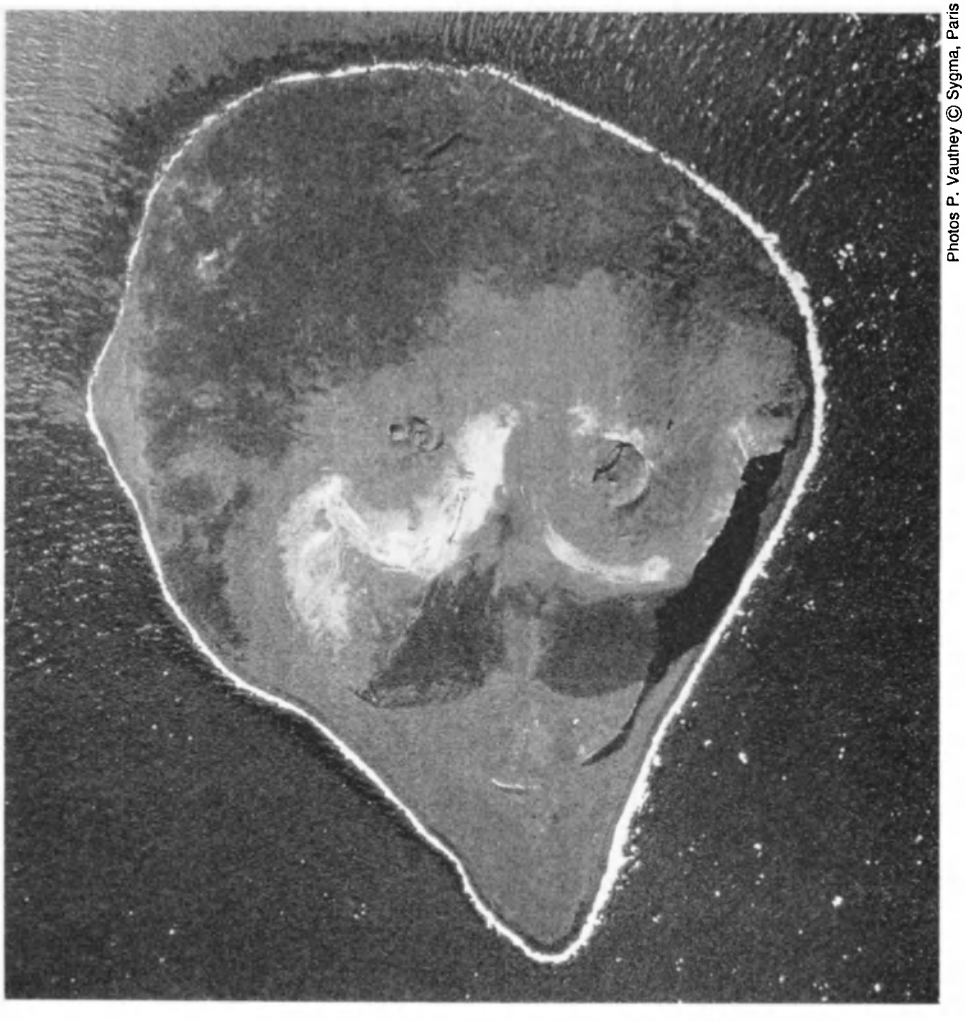


Map © Geological Museum, London



Birth of an island

On 14 November 1963, a fiery eruption in the Atlantic Ocean off the southern coast of Iceland heralded the birth of a new island. Named Surtsey, after Surtur, the fire god of Icelandic myth, the new island rose from the water in a convulsion of flame and steam. A week after the eruption Surtsey had a surface area of 70 square metres and within three and a half years had grown to its present size of two and a half square kilometres with elevations of up to 173 metres. When scientists visited the island after it had cooled, they were astonished to find that plant life had already established a footing. Constituting as it does the first "virgin" ecosystem known to man, Surtsey is now the site of a long-term ecological research programme.



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Cry havoc!

Although prediction of volcanic eruptions can reduce or prevent loss of life, little can be done to control damage to crops or property once an eruption is under way. The three major dangers arise from mud-flow, lava-flow and ash.

Over the last few centuries mud-flows (sometimes known as lahars***) have proved to be the most dangerous, killing more people and destroying more property than any other type of volcanic activity. Mud-flows often result from the rapid melting of ice or snow on the slope of a volcano or may be due to heavy rain or snow falls after an eruption on new volcanic ash. Mud-flows have been known to attain speeds of up to 70 kilometres an hour and to travel as***

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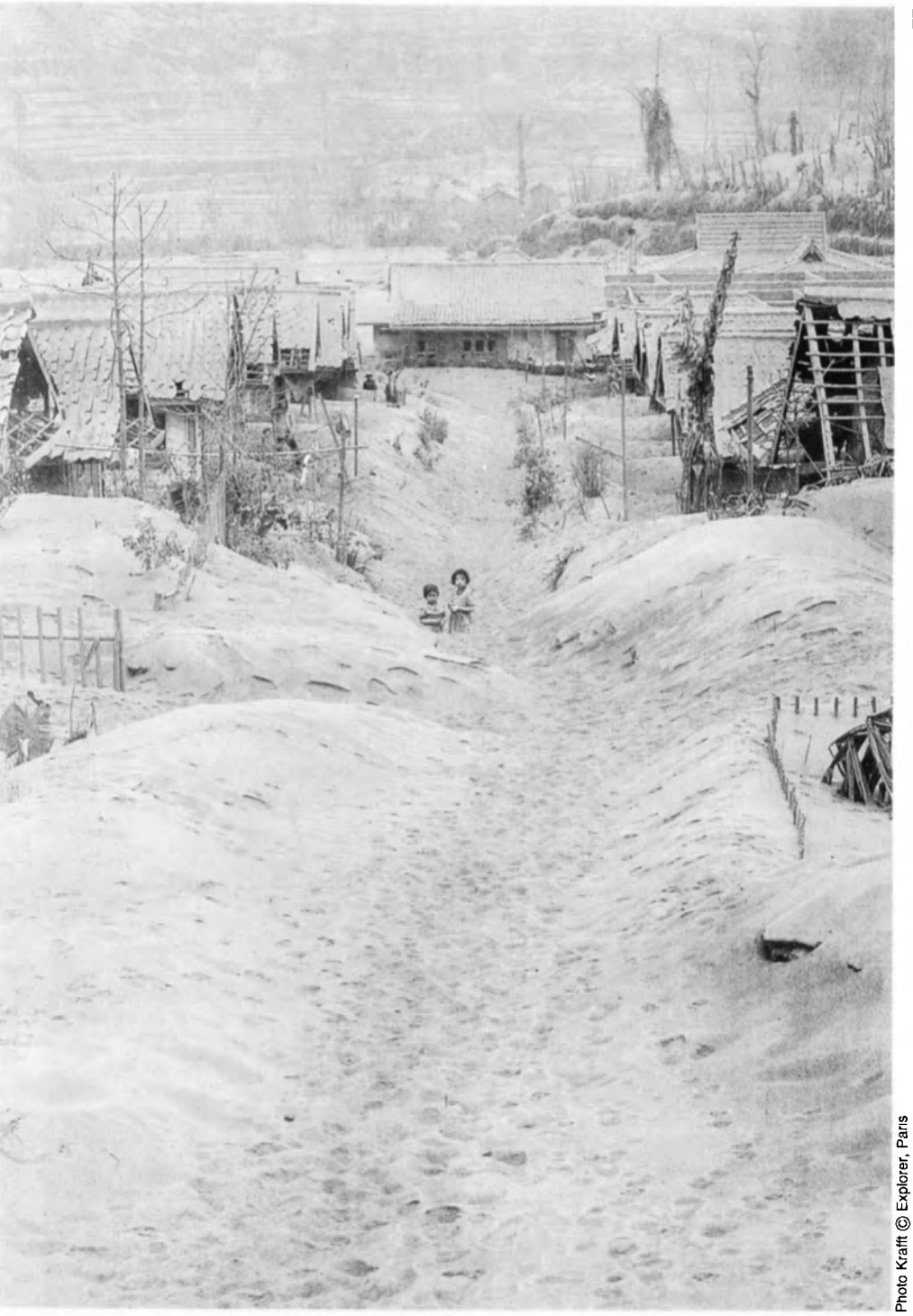

Photo Krafft © Explorer, Paris

far as 180 kilometres. Left, the town of Armero, Colombia, swallowed up by mud following the eruption of the Nevado del Ruiz volcano, in November 1985.

Thin lava-flows cool fairly quickly, but thicker flows may take years to cool completely. Various methods have been attempted to check or divert lava-flows, including the use of water hoses to create a solid wall of cooled lava and bombing the sides of a flow to split it into many smaller flows. Above left, lava-flow blocks a road following the eruption of La Fournaise volcano on the French island of Réunion in the Indian Ocean, on 18 March this year.

Despite its name, volcanic ash is not the product of burning; it consists of pulverized lava and fragments of rock thrown into the air by the sudden explosive escape of volcanic gas. The eruption of the Tambora volcano on the northern coast of the island of Sumbawa, Indonesia, in 1815, which killed 50,000 islanders, is estimated to have had an explosive force equivalent to 16,000 megatons. The very fine ash from such an eruption may travel huge distances and affect weather patterns. Above, the village of Parentas, Indonesia, enveloped in volcanic ash following the eruption, in 1982, of the Galunggung volcano.

▶ is extremely difficult in view of our present lack of sufficient research data and experience in this field. And without correlation to enable him to establish links of cause and effect between what he has been able to measure and observe, it is virtually impossible for the volcanologist to establish a serious diagnosis.

Finally, I would like to remind readers of an article by me which appeared in the October 1967 issue of the *Unesco Courier*. In it I drew the attention both of politicians and of the inhabitants of the regions involved to the great danger of so-called "extinct" volcanoes. These volcanoes are often, in fact, only dormant, which implies that they will one day become active again. This is a risk which should be taken seriously and construction should be avoided within the danger zone surrounding such volcanoes.

The extent of the danger zone will depend on the nature of the volcanic activity (whether it is effusive or explosive), the size and altitude of the volcano concerned, and even the climate of the region in which it is situated.

The importance of climate and altitude was demonstrated in dramatic fashion on 13 November 1985 with the eruption of the Nevado del Ruiz volcano in Colombia. Had it not been for the height of the volcano and the climate of the region, which made possible the formation of a thick icecap on its summit, the upsurge of lava at a temperature of 1,000 degrees Centigrade would not have provoked the melting of hundreds of thousands of cubic metres of ice and the formation of "lahars", those terrible torrents of volcanic mud which swallowed up the town of Armero, claiming the lives of 23,000 victims.

What I wrote almost twenty years ago about the danger represented by Vesuvius (Italy) or the Campi Flegrei (the Phlegraean Fields, Naples, Italy), Mount Fuji (Japan) or Mount Rainier (USA), remains true today, as witness what happened at Mount St. Helens, a close neighbour of Mount Rainier, and at Helgafell in Iceland. The authorities of countries within whose borders potentially dangerous volcanoes are situated—those thought to be extinct as well as those known to be active, such as Merapi (Indonesia) or Etna (Italy), Sakurajima (Japan), Vulcano (Italy) or Pichincha (Ecuador), to name but a few—should take advantage of the "days of peace" to consider the problems that will arise and prepare the action they will take when these sleeping giants reawaken. ■

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The evolution of life

Quaternary. Large mammals like mastodons (A), sabre-tooth cats (B), and blue whales (C) are at first dominant. For the last million years, ice intermittently covers most of the northern hemisphere. Some animals migrate; some, like woolly rhinoceroses (D), adapt to the cold. Early man (E), using stone tools and making fire, is succeeded by modern man.

Tertiary. Mammals evolve rapidly, producing such specialized types as the lemur *Plesiadapis* (A), ancestor of the primates, five-toed *Phenacodus* (B) and horned *Titanotherium* (C). Birds evolve, including giant flightless forms like *Diatryma* (D). Fish, reptiles and invertebrates now resemble those of today; for example, the sand shark (E) has hardly changed.

Cretaceous. On land, flowering plants like magnolia (A) appear. In the sea, modern bony fishes evolve alongside sea-urchins (B) and bivalve molluscs (C). At the end of the period, giant dinosaurs, like *Stegosaurus* (D), and large flying pterodactyls (E) suddenly die out. New types of small mammal, such as the shrew-like *Phascolotherium* (F), evolve.

Jurassic. The sea shelters brachiopods, cephalods called *ammonites* (A), belemnites (B) and fossil oysters such as *Gryphaea* (C). There are bony fishes, sharks and two groups of marine reptiles: ichthyosaurs (D) and plesiosaurs. Great dinosaurs like *Brontosaurus* (E) share the land with small mammals. *Archaeopteryx* (F), the ancestral bird, takes wing.

Triassic. Such mammal-like reptiles as *Cynognathus* (A), ancestors of the mammals, are succeeded by small animals, dinosaur-ancestors like *Ornothosuchus* (B). Clubmosses, horsetails and seed ferns become rarer; they are replaced by cycads, ginkgoes (C) and conifers. In the sea, new invertebrate groups evolve. Sea-lilies (D) and reef-building corals are numerous.

Permian. Mammal-like reptiles like *Dimetrodon* (A) rule the land. Large amphibians are scarce. In the sea, cephalods (B), two-valved molluscs (C) and primitive bony fish (D) continue to thrive; corals and sea-urchins grow scarcer, and most of the sharks die out. A forest of seed ferns covers the southern land mass. More varied plant life flourishes in the north.

Carboniferous. The amphibians (A) become a large and important group; they eventually give rise to the reptiles, the first full-time land vertebrates. Conifers and tree ferns (B) evolve, and dragonflies (C) and other insects appear. Sharks (D) dominate the sea. In shallow water, brachiopods (E), corals (F), cephalopods, sponges and sea-lilies are common.

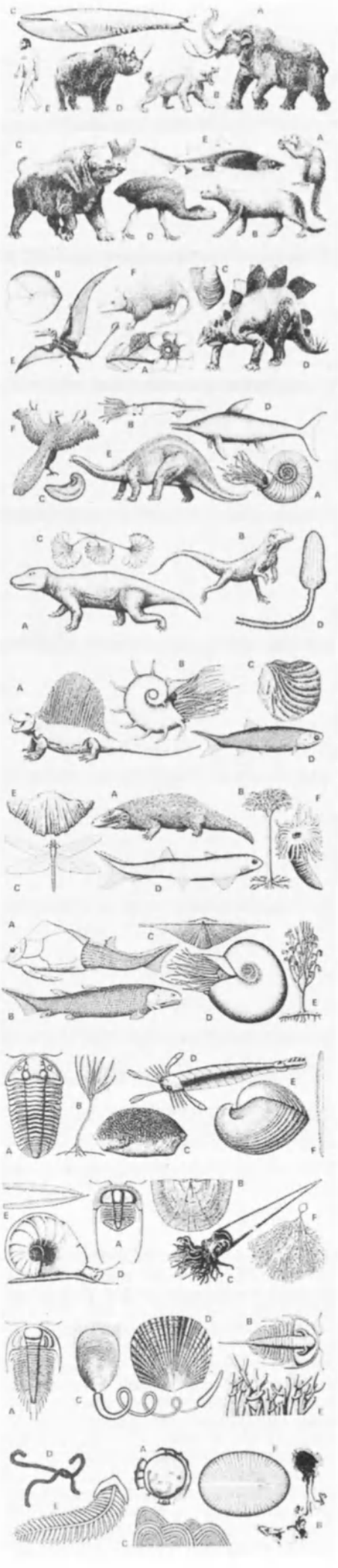
Devonian. Armoured fish (A) and bony and scaly fish (B) flourish in fresh water. Sharks and spiny fish colonize the sea. Brachiopods (C) and molluscs called cephalopods (D) continue to evolve; trilobites grow scarce and graptolites die out. On land, simple vascular plants (E) are followed by clubmosses, horsetails and ferns. The first amphibians evolve from scaly fish.

Silurian. The land is conquered, first by colonies of seedless vascular plants and later by scorpion-like arthropods. In fresh water, small fish and large eurypterids or water-scorpions abound. The sea is teeming with invertebrates, especially trilobites (A), crinoids or sea-lilies (B), corals (C), horny-coated eurypterids (D), brachiopods (E) and graptolites (F).

Ordovician. Shelly invertebrates flourish, especially trilobites (A), brachiopods (B), cephalopods (C) and gastropods or sea-snails (D). Corals, two-valved molluscs and branchy or mossy colonies of bryozoans appear. Graptolites (E, F), some looking like hard spider webs, spread. In fresh water the first fish (known only from scale fragments) evolve.

Cambrian. At the dawn of this period a number of animal groups develop shells and hard parts of calcite and horn. These include trilobites (A, B), brachiopods (C, D), sponges (E) and crustaceans. The trilobites, so called from their three-lobed bodies, evolve into a large and varied group of crawlers and swimmers that dominates the sea for the next 100 million years.

Precambrian. During this period, which goes back to the beginning of geological time, complex organic compounds evolve from simple inorganic chemical substances. Bacteria (A, B) and algae (C, D) appear early in the period. By its close, soft-bodied marine and freshwater animals like worms (E, F), jellyfish and sponges have evolved.



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Life from space

Does life on Earth have its origins in comets?

by Chandra Wickramasinghe

Since 1962, astronomers Professor Chandra Wickramasinghe and Sir Fred Hoyle have been studying the nature of interstellar dust and have concluded that terrestrial life had its origins in the gas and dust clouds of space. Life, they believe, in direct contradiction to Darwinian theory, was derived from and continues to be driven by sources outside the Earth (see the *Unesco Courier*, May 1982). Although their conclusions are strongly contested by other scientists, initial appraisal of data obtained from the study of Halley's comet appears to lend support to at least some aspects of their viewpoint.

COMETS are inextricably linked with the history of the Earth. Cometary bodies, as well as debris from them in the form of fine dust particles, have been colliding with the Earth from the very earliest days of its existence as a planet some 4,600 million years ago. It is now clear that volatile materials from comets, including water, contributed in significant measure to the primordial oceans and atmosphere.

Cometary impacts and the acquisition of cometary material did not, however, stop in distant geological time. As recently as 1908, a comet, or part of a comet, collided with the Earth in the Tunguska Valley of Siberia, exploding at a height of 8.5 kilometres in the atmosphere and devastating hundreds of square kilometres of taiga forest.

The entire Solar System today is surrounded by a spherical halo of some thousands of millions of comets located at a distance of about a tenth of a light-year (a light-year is the distance light travels in a year—about 10 million million kilometres). Passing stars cause cometary objects from this halo to become deflected into orbits that bring them to the inner regions of the Solar System at the rate of about one or two a year. The Earth is well and truly entwined within these orbits so material shed from these comets must be reaching us quite plentifully. This material becomes trapped in the Earth's upper atmosphere, adding steadily to the store of terrestrial volatile materials. Fluctuations must occur in the rate of in-fall of cometary debris over long periods of geological time. It is now widely believed that significant increases in this rate would trigger the onset of episodes of global glaciations (ice ages) such as are known to have occurred.

A typical comet, such as Halley's comet, has a mass of some 100,000 million tons and a direct hit from such an object would have dramatic consequences for our planet. Fortunately, such collisions are exceedingly rare, occurring at intervals averaging about 300 million years, coinciding approximately with the time intervals between successive bursts in the evolution of terrestrial life. Smaller comets are more numerous and could collide more frequently.

This much is more or less agreed upon by most scientists. A less popular view, advocated by the British astronomer Sir Fred Hoyle and myself, is that comets were also responsible for the importation of organic molecules that contributed to the origin of life on our planet. We have further suggested that the Earth continues to receive ready-formed living structures such as bacteria and viruses even at the present time.

From 1975 onwards, we have accumulated evidence to support our view that organic dust grains, including organic polymers (large chains of carbon-based organic molecules), exist on a vast cosmic scale. These dust grains populate the clouds of gas that exist between stars and give rise to the visual effect of dark patches and striations seen against the diffuse light of the Milky Way. In 1981, through a combination of laboratory studies, mathematical computations and astronomical observation, we arrived at the conclusion that the bulk of cosmic dust was not merely organic but distinctly biological in character [1].

In a series of publications we have presented arguments to support the theory that life on Earth had its origins in comets and that evolution is controlled by the continuing input of cometary material. Because the injection of comets from the outer Solar System is sporadic, this input of cometary material is not expected to be uniform and regular in time, and so the effect on evolution will also be sporadic. This sporadic characteristic clearly shows up in the fossil record which traces the evolution of terrestrial life.

A dramatic example is provided by the extinction of the dinosaurs 65 million years ago. It has recently been argued by many scientists that this event was caused by a comet which shrouded the Earth in a halo of fine particles. These particles acted like a smog that darkened the skies for decades and caused withering of plankton and plants and the demise of all large creatures that fed on plants.

Sir Fred Hoyle and I believe that such a purely physical cause is unlikely in view of the fact that the extinction of the dinosaurs also coincided with an extinction of a large fraction of the genera of all plants, animals and micro-organisms and the emergence of several brand new orders of living forms. We identify this extinction/speciation event of 65 million years ago with a genetic storm that resulted from an exceptionally large new crop of comets that were injected into the inner regions of the Solar System.

The first clear-cut detections of organic molecules—hydrogen cyanide (HCN) and methyl cyanide (CH_3CN)—came from observations of comet Kohoutek, in 1973 and 1974. But cometary theories came under very much closer scrutiny in March this year when, as the culminating point of the International Halley Watch, the European space satellite *Giotto* penetrated to within a few hundred kilometres of the nucleus of Halley's comet (see the *Unesco Courier*, March 1986).

The payload of *Giotto* included a variety ▶

(1) The adjective "organic" is often commonly used to mean "living", in the sense that a plant, a tree or a human being is "living"; chemists employ it in a restricted sense to describe compounds containing carbon combined with hydrogen. All living things contain carbon and hydrogen and thus are organic, but not all things that contain carbon and hydrogen are living. "Biological" means "of or relating to life or living things".

Photo © APN, Moscow

On the morning of 30 June 1908, a huge aerial explosion with an energy equivalent to that of 10 to 15 megatons of TNT devastated some 2,000 square kilometres of pine forest (left) near the Tunguska River in central Siberia. The explosion is thought to have been caused by a comet, or a fragment of a comet, colliding with the Earth. An object such as this would have disintegrated in the Earth's atmosphere creating a fireball and a powerful blast wave but no crater.

▶ of scientific experiments and a video camera that was intended to send back colour pictures of the comet's nucleus. Earlier in March, the Soviet space satellite *Vega 2* successfully accomplished a similar mission. Pictures of the comet's nucleus, taken by *Vega 2* from a distance of several thousand kilometres, showed tentative indications that it may be split into at least two fragments. *Giotto* might have been able to settle this matter but for an unfortunate hitch in communications that occurred seconds before the moment of closest approach. In the event, the best pictures we have is of the nucleus surrounded by a peanut-shaped shroud of obscuring dust.

What is to be learned from the first appraisals of the data sent back by the various missions to comet Halley?

Our organic theory of comets predicts that cometary nuclei must develop a highly porous mesh-like surface layer of polymeric particles. Evaporation of material on a large scale can only occur from places on the surface where this surface layer becomes abraded or broken. A consequence is that cometary nuclei must have exceedingly black, non-reflective surfaces, a property we predicted only weeks before the *Giotto* encounter.

The *Giotto* pictures showed a few places where the nucleus could be seen through "holes" in the dust halo, and the surface showed up as amazingly black—*Giotto* investigators described it as being "blacker than the blackest coal". This was indeed a triumph for the organic model.

More triumphs were to follow. *Giotto's* particle impact analyser was equipped to determine the chemical make-up of the cometary dust particles by measuring the distribution of the masses of atoms within them. J. Kissel, the principal investigator on this experiment, reported on 17 March that analysis of one per cent of the total data record indicated that the dust was made up of the elements carbon, oxygen, nitrogen and hydrogen with very much smaller amounts of other chemical elements. Two logical possibilities follow from this data. These atoms can exist in the form of volatile ices such as water, carbon dioxide and ammonia together with simple hydrocarbons such as methane, or they could occur in the form of highly stable organic polymers. Since, in other experiments, the temperature of these particles was measured at 125 degrees Celsius, well above the boiling points of ices and simple hydrocarbons, it follows that the cometary particles could only be made of organic polymers.

Both *Vega 2* and *Giotto* experiments indicated that hydrogen atoms, hydroxyl radicals and water molecules were also released quite liberally from the comet. However, the amounts of these substances were not inconsistent with the water associated with living cells (60 per cent by volume of such cells is water). Significantly there was no evidence whatever for a halo of icy particles around the nucleus which is predicted by the widely accepted "dirty snowball" cometary theory first propounded by US astronomer Fred Whipple.

Scarcely two weeks after the *Giotto* rendezvous an important observation of the comet in the infra-red region of the spectrum was made by astronomers Dayal Wickramasinghe and David Allen, using the 154-inch Anglo-Australian telescope at Siding Springs, New South Wales. They discovered remarkably strong signals due to emission from heated organic dust over the wavelength range from 2 to 4 micrometres. Basic structures of organic molecules involving linkages between carbon and hydrogen atoms (CH bonds) absorb and emit radiation at wavelengths near 3.4 micrometres; for any assembly of complex organic molecules such as bacterium this absorption band is in general very broad and takes on a highly distinctive profile. The most remarkable fact that emerged was that the profile of this emission from Halley's comet matched precisely the behaviour of a dried-out bacterium as measured in the laboratory.

Although a full appraisal of the recent observations of comet Halley cannot yet be offered, it is already clear that a few quite remarkable facts have emerged. The comet is clearly not an inorganic dirty snowball as most astronomers had previously held. It is organic. Within a mammoth chunk of organic matter, some 8 kilometres long and 4 kilometres wide, a large proportion of water molecules and traces of other materials are also trapped. Whether one likes it or not, the organic material of the comet occurs predominantly in the form of particles whose absorption properties, sizes and densities are identical to the predictions of a bacterial model.

Interpreted in the most conservative possible way, the latest discoveries indicate at the very least that comets could have provided the raw materials, the organic building blocks from which life emerged on the Earth. More realistically, in my view, the data point in a decisive way to life in the form of bacteria and viruses being contained in comets and brought by them to the Earth. ■

NALIN CHANDRA WICKRAMASINGHE *is professor of applied mathematics and astronomy at University College, Cardiff, Wales, and Director of the Institute of Fundamental Studies, Sri Lanka. In 1962, while at Cambridge University, Professor Wickramasinghe, who is of Sri Lankan origin, was awarded the Powell Prize for English poetry. His views on the space origins of terrestrial life are fully developed in two books,* Space Travellers: the Bringers of Life *and* Evolution from Space, *of which he is the co-author with Sir Fred Hoyle.*

The hand of man

by Stephen Boyden and Malcolm Hadley

THE human species evolved late, very late, in the history of our planet; but during man's short time on Earth, his hand has wrought pervasive change—in air, water and soils, in other living creatures, in the whole tightly connected system of interacting parts of which the environment consists—and this in but the last instant of geological time.

The history of man's changing relationship with his habitat—in terms of both the impact of human society on the natural environment and the conditions of life of human beings—can, at the risk of oversimplification, be divided into four distinct but overlapping ecological phases: the *Primeval Phase,* the *Early Farming Phase,* the *Early Urban Phase* and, finally, the *Modern Industrial Phase.*

During the **Primeval Phase**—sometimes also called the pre-domestic or hunter-gatherer phase—human populations probably differed little from those of other omnivorous mammals in the extent and nature of their interaction with the ecosystems of which they were a part. As hunter-gatherers they had their natural place in the food cycle, deriving their energy, in chemical form, from natural foodstuffs of animal and plant origin. They in turn provided food for other predators and their remains were returned to the soil through the processes of decomposition. The amount of energy used by an early hominid group in its natural habitat would have been more or less equivalent to the energy value of the foodstuffs consumed by members of the group. In short, our ancestors fitted into their environment in much the same way as any other animal species.

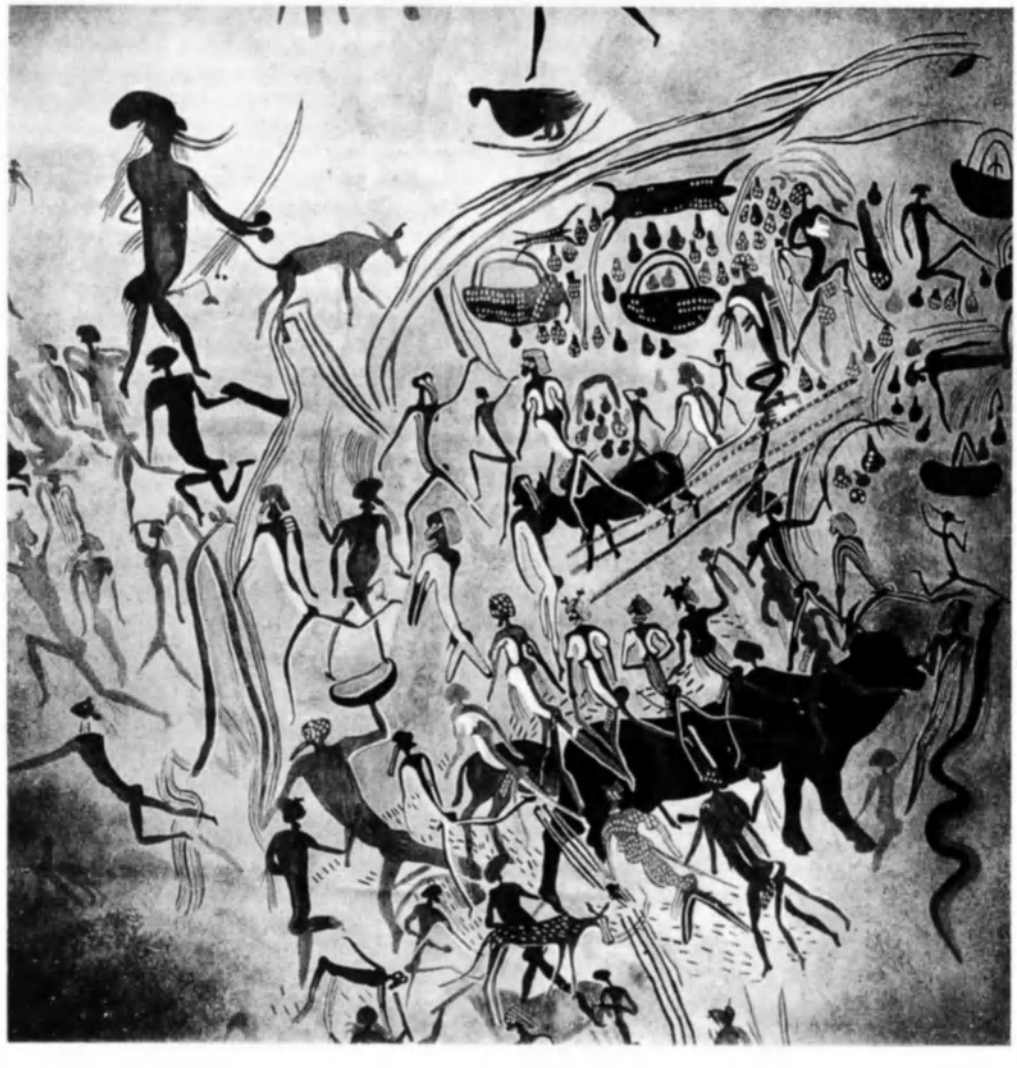
Then, probably about half a million years ago, in the volcanic lands of the East African rift valleys, man began to use fire, deliberately and regularly, both for protection and as a means of obtaining and cooking food. Fire was used to drive game out of the undergrowth and to attract animals to the fresh herbaceous growth that sprang up on ground cleared by fire.

This was a highly significant development with considerable ecological impact. Forest and grass fires became much more frequent events, bringing about important changes in the plant cover of certain areas of the Earth's surface. Suddenly, human societies were using considerably more energy than previously, since the flow of "somatic" energy (the energy that flows through the bodies of human beings for metabolism, physical work and growth) was now supplemented by "extra-somatic" energy (energy such as that derived from fuel, which does not flow through living organisms).

The use of fire thus brought about a qualitative change in the relationship between the human species and its environment. The ecological consequences were restricted to the destructive effects of fire itself, and the chemical products of the combustion of wood (mainly carbon dioxide) were easily absorbed into the system as a whole with negligible repercussions. Nevertheless, the use of fire is an early and clear example of man's potential as a modifier of the environment. Man had already become a significant ecological force, and human groups no longer fitted into their local ecosystems in quite the same way as other animals.

In addition to fire, the most significant ecological effect of man on the environment during the primeval phase was probably the spread of the human species itself. Man appears to have roamed the open African savannah until about one million years ago, when he fanned out into a great variety of other habitats—arid steppes, high altitude grasslands (in Ethiopia) and forest grasslands. Following these initial excursions, man ventured further out into a wide range of different climatic and ecological settings in all five continents of the world. ▶

Photo © Almasy, Paris



Rock painting dating from about 2000 BC, from the Rusape area of Zimbabwe. The way of life represented is that of Late Stone Age hunters. Bushmen were still making paintings like this in the 19th century, but some of the surviving examples may have been the work of southern Bantu peoples.

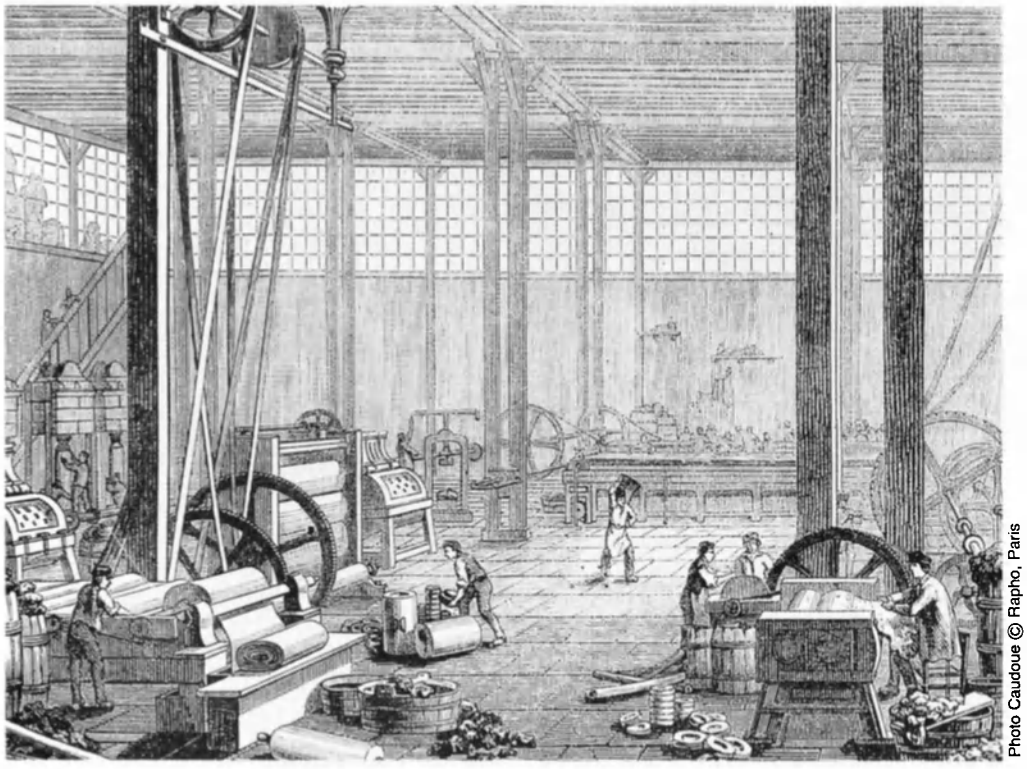


Photo Caudoue © Rapho, Paris

Engraving by the Swiss artist Aloys Fellmann (1855-1892) depicts men at work in a typical 19th-century factory at a time when the industrial revolution was gathering momentum in Europe.

▶ The **Early Farming Phase** began, in some regions of the world, about 12,000 years ago. With the domestication of animals and plants, for the first time in the story of the Earth, a living creature came, quite consciously and deliberately, to manipulate the biological processes of nature for his own purposes.

As domestication spread and farming techniques advanced, the total impact of human society on the environment increased significantly. The face of the Earth was beginning to be changed by the hand of man, to the extent that, in the northern hemisphere, vast areas of forest land disappeared, to be replaced in some instances by farming land and in others by less luxuriant and more open vegetation. In some cases, man's agricultural activities triggered massive erosion. In eastern Fiji, for example, where man arrived some 3,000 years ago, at least 50 centimetres of soil was lost in a period of 150 years, from between 1,900 and 1,750 years ago.

Among other important implications of farming practices was the introduction of monoculture food crops, on which many populations came to be almost entirely dependent for sustenance. This development clearly had some practical advantages, but it also involved serious risk, since, if the monoculture crop failed for any reason, then widespread starvation was virtually inevitable.

One further consequence of mankind's deliberate manipulation of biotic processes is worthy of mention. Selective breeding of animals and cultivation of plants for desirable qualities relating to food production brought into existence a range of forms of life which would otherwise never have seen the light of day.

Fire, of course, remained in use during this second ecological phase and it came to play an important role in the manufacture of metal implements. With the invention of such devices as watermills, windmills and sailing ships, extra-somatic energy came to be used for performing work of various kinds. Compared with what was to happen later, however, the ecological impact of these machines was relatively slight, being restricted mainly to the role that ships played in the migratory movements of the human species, the geographical spread of technologies and the re-distribution of some animal and plant species.

Human groups became much less nomadic than in the primeval phase, although the length of time they remained in one place depended to some extent on the kind of farming they practised. The new lifestyle had significant consequences for the interrelationships between human populations and microbial and other parasites and pathogens. In some areas, for example, malaria and schistosomiasis became important causes of ill-health and death, partly counteracting the reduced mortality resulting from the protection which the new living conditions gave against some of the hazards of life experienced in the primeval phase.

Despite all the changes that agriculture produced, the early farming phase shared two important ecological characteristics with the primeval phase which are not features of modern societies. First, the rate of use of extra-somatic energy (mainly fire) paralleled the rate of increase in the human population. Second, man's activities did not interfere significantly with the natural biogeochemical cycles of the biosphere, such as the carbon, nitrogen and phosphorus cycles.

The **Early Urban Phase** started about 5,000 years ago, with the establishment of the first cities in Mesopotamia and, not long after, in China and India. These early cities ushered in the third ecological phase of human existence, which was marked by a series of fundamental changes affecting the organization of human society and the life experience of its members. Some, but not all, of these changes have persisted and remain features of many urban settlements in the modern world.

The most obvious changes were simply the huge increase in the number of people gathered together in one place and the fact that the majority of their inhabitants were not directly involved in such subsistence activities as farming, fishing and hunting. The urban populations were supported by food surpluses produced by nearby farmers who lived and worked beyond the city walls.

Because many urban populations came to rely for their sustenance on a single staple food, such as rice, maize, a cereal grain or potatoes, there was a narrowing of the range of foods consumed by individuals. Specific deficiency diseases, including rickets, scurvy, beri-beri and pellagra, were common in different parts of the world. There was a constant threat and repeated occurrence of famine, since urban populations did not have a wide range of alternative sources of food to turn to when one supply failed.

Increased population density had a marked effect on the interrelations between human populations and potential parasitic or pathogenic organisms. Pestilence became one of the major facts of life. Typhus, cholera, typhoid, the plague, smallpox, malaria, infant diarrhoea and many other infectious diseases were a constant cause of fear and alarm and were among the main causes of death.

One of the most significant biosocial developments which accompanied early urbanization was the advent of job specialization. Some degree of specialization existed in the early farming and even in the hunter-gatherer societies, but, apart from the sex-based division of labour, most people were jacks-of-all-trades. It was during the early urban phase that specialization really came into its own.

Part of the ecological importance of this development lies in the fact that, for the first time in human history, different groups within a single society experienced quite different conditions of life. Job specialization led in turn to a reinforcement of the tendency of human societies to establish hierarchies. Instead of being relatively spontaneous, transient and dependent upon the nature of the task in hand, the hierarchical structure of society became much more rigid, more extreme and more permanent. It frequently came to be determined by heredity rather than by common consent based on ability and personality.

Urbanization also introduced entirely new concepts of ownership. In primeval times, an individual "owned" only those possessions he had made himself and no more than could be easily carried when he moved from one camp site to another. In the early farming phase, animals, crops and stored grain became the objects of ownership, but, at least in the early stages, this was usually communal ownership. In early cities, individual and family ownership be-

Photo Bossu © Sygma, Paris

Highway intersection at Villefranche, near Lyon, France—a typical construction of our modern, energy-hungry, industrial society.

came very important and has remained so ever since in many parts of the world.

As in the preceding phases, the natural biogeochemical cycles were still intact, and the rate of energy use by society still paralleled changes in population size. The biosphere as a whole and most of the ecosystems to which human populations belonged were, despite some short-term fluctuations, still essentially in a state of dynamic equilibrium. The existence of cities did not, of course, mean an end to self-sufficient subsistence agricultural societies, which indeed continue to exist in some areas of the world today.

Until very late in this period, few cities contained many more than 100,000 inhabitants. One notable exception was Rome, which, around the time of Jesus Christ, had a population of about one million. However, although cities have until very recently contained only a very small percentage of the total human population, they have had an ecological impact out of all proportion to the number of people living in them.

The **Modern Industrial** or **Technological Phase** began with the so-called industrial revolution. This industrial transition, as we prefer to call it, started in Europe and in North America some 150 to 200 years ago and is still taking place in many parts of the world. Though it began only seven or eight generations ago, this phase has had an impact on the Earth and its workings quite disproportionate to its duration. Its ecological characteristics are not shared with any of the preceding phases of human existence. This is most strikingly illustrated by the present situation regarding population, energy and the biogeochemical cycles.

While the early farming and early urban stages provided protection from some of the causes of death that characterized the primeval stage, they were associated with new causes of mortality in the form of malnutrition and pestilence. In the modern industrial phase, greatly improved knowledge of the nutritional requirements of our species, and new practices in public health and medicine, including the pharmaceutical revolution, have resulted in a remarkable change in population dynamics. As a consequence, the human population is now doubling at the rate of once every thirty-five to forty years, in contrast to the overall rate of once in 1,500 years during the early farming and early urban phases.

Another outstanding feature of the modern industrial phase, and one which determines many of its other characteristics, has been the massive introduction of machines and manufacturing processes powered by extra-somatic energy. The chief sources of this energy have been the fossil fuels, beginning with coal, but with petroleum products and natural gas now more important. In some places, hydroelectric power makes a significant contribution and nuclear power is rapidly coming to the fore. In highly industrialized countries like the United States, the amount of power used on a *per capita* basis is now thirty times greater than it was prior to the industrial transition.

Thus, unlike the situation in the earlier phases, the rate of increase in energy use in the modern industrial phase no longer matches the rate of increase in population, and the ratio of extra-somatic energy used by society is continually increasing. Globally, the amount of energy flowing through human society is doubling about twice as fast as the population.

In many areas the natural biogeochemical cycles are no longer intact. Interference with the carbon and phosphorus cycles, for example, may well give rise to very serious ecological problems in the future. In the case of the nitrogen cycle, vast amounts of nitrogenous waste products of human communities, which in previous eras were returned to the soil, are now lost to rivers and oceans, and industrial processes are discharging substantial quantities of nitrogen oxide into the atmosphere.

A significant change of a qualitative nature has been the synthesis, often in very large amounts, of thousands of new chemical compounds, many of which have potent effects in biotic systems. Vast quantities of these synthetic chemical substances are finding their way into the oceans, the soil and the atmosphere and, of course, into living organisms.

Complexity and unpredictability are two other characteristics of the present phase of human existence. Modern technology and the economic web of interdependence of countries are making problems of land use and resource management much more complex than they were even a generation ago. Machines are now available, for example, for clearing large areas of forest in a very short space of time. With modern communications technology, a decision taken now in a financial centre in a temperate zone can lead to the felling, within a week, of a tropical forest tree 10,000 kilometres away which has taken one hundred years to grow.

If certain widely accepted predictions about future increases in the level of energy use turn out to be correct, by the year 2050 mankind will be using about as much energy as is used by all other animals and plants put together. One does not have to be a specialist to see that this kind of growth in energy use, and the concomitant increase in the use of resources and the outpouring of wastes, cannot go on indefinitely.

Opinions differ as to how much longer the biosphere is likely to be able to tolerate the ever-increasing load which human society is placing on it. There are some who believe that mankind is incapable of bringing under control the accelerating processes which threaten the collapse of the biosphere and civilization and that the collapse of the system will be total and will involve the extinction of the human species. Others are more optimistic, believing that man, with his great ingenuity, will succeed in reaching a new ecological equilibrium before it is too late. ■

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1986: Year of Peace / 7

Over 400 representatives of 115 international non-governmental organizations and 71 national organizations from 36 countries attended "Together for Peace", a Conference held in Geneva from 20 to 24 January 1986 to mark the International Year of Peace. Topics discussed at the Conference, held under the auspices of the Board of the Conference of Non-Governmental Organizations in Consultative Status with the Economic and Social Council of the United Nations, included questions of disarmament, development, social progress, justice, human rights, satisfaction of basic human needs, and preparation of societies for life in peace. At the end of the Conference, the following appeal was adopted by acclamation.

We appeal to all people of the world to join in a common pursuit of peace.

With just a decade and a half for this century to come to a close, we are convinced of the duty and obligation of all people to make concerted efforts to usher in a world of peace as the new century opens. We are convinced that it can be done, that the present dangerous trends in world affairs can be stopped and reversed. We see signs of hope in the new spirit of dialogue and openness among leaders of nations and in the determination of the people to attain peace.

We do not have to recount the threats to peace. The race towards nuclear catastrophe is keeping up its momentum. As if the earth and the oceans can no longer bear the weight of weapons outer space is explored for stationing of arms. Hundreds are killed every day by non-nuclear weapons. Hunger takes its daily toll of thousands. Millions are deprived of basic human needs and fundamental human rights. Millions still groan under domination and exploitation. Apartheid continues, denying justice, destroying people and destabilizing nations.

We appeal therefore to work together for a world of peace, not where war is merely absent, not where human survival is just possible, but where justice prevails and human dignity is upheld.

We reiterate that the nuclear arms race constitutes the greatest threat to peace and survival. Our appeal therefore assumes a special urgency in this regard. ...

As we pledge to work together for disarmament we appeal to all to join in and support efforts for an immediate end to all nuclear weapon tests, a comprehensive test ban treaty, the prevention of an arms race in outer space, elimination of chemical weapons and all other weapons of mass destruction, and substantial reduction in conventional weaponry. We believe that it is possible to implement a systematic and credible programme for the elimination of nuclear weapons by the end of the century.

We believe that peace is inextricably interlinked with development and social progress and that its foundation is justice. Deprivation and disparity are threats to peace. We therefore call for a strategic development initiative for a new international economic order that ensures just economic relations between and within nations. We further appeal for genuine respect of the rights of people to decide their own destiny, their rights to self-determination and interdependent development, non-interference in their internal affairs, in conditions of security and social progress.

We emphasize that the exercise of human rights and freedoms is an essential element of peace. Violations of them are a major cause of armed conflicts. The fuller the rights that every person enjoys in society, the more stable that society will be; the fuller the implementation of human rights globally, the more stable international relations will be. ...

We recognize that peace is an essential requirement for the satisfaction of basic human needs such as food, shelter, health, education, labour and environment. As we commend recent co-operative actions across continents to meet emergency needs for food, we appeal for more systematic and concerted attempts to prevent death by starvation and for the adoption of long-term policies nationally and internationally to ensure food for all.

We call for joint actions to promote substantial reduction of military expenditures with a view to rectifying the current distortion in the use of resources. We agree that every gun that is made, every warship launched, every rocket fired, signifies in the final sense a theft from those who hunger and are not fed, those who are cold and are not clothed.

Recognizing the importance of preparation of societies for life in peace we call for a new orientation in education, science, culture, religion and mass media towards peace-making.

The resources available in these areas can be more constructively utilized for peace. ...

Nations must seek peace together. We can only create a common future if we can cope with the common crisis we face and build peace on the basis of the concept of common security. We appeal for a greater commitment to international co-operation for which the universal instrument is the United Nations. We pledge our continued support to the United Nations and its agencies. ...

We realize that the odds are tremendous. But we are confident that the determination of the people to achieve peace will prevail. We have optimism and hope because we are together for peace. It is in that spirit that we renew our commitment to peace and invite you all, all peoples of the world, to join in the challenging tasks ahead. ■

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The Earth on fire

Glowing streams of molten lava pour from the Hawaiian volcano Mauna Loa during an eruption in 1984.
(See article page 27).

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